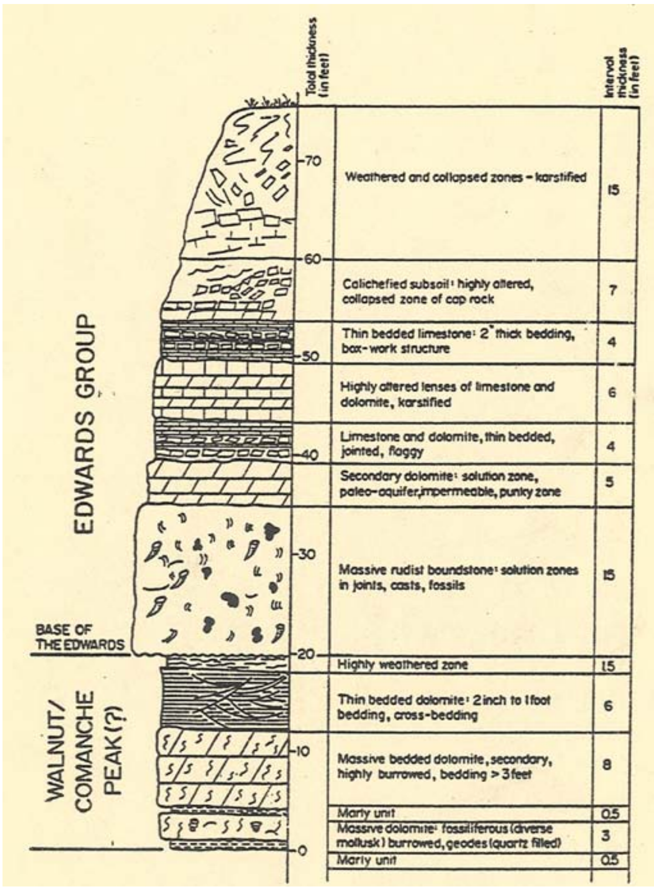
# EDWARDS AQUIFER--WATER QUALITY AND LAND DEVELOPMENT in the AUSTIN AREA, TEXAS

David A. Johns and C.M. Woodruff, Jr.




FIELD TRIP GUIDEBOOK

GULF COAST ASSOCIATION OF GEOLOGICAL SOCIETIES
44th ANNUAL CONVENTION
AUSTIN, TEXAS

5 October 1994

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*"As for me," said the little prince to himself, "if I had fifty-three minutes to spend as I liked, I should walk at my leisure toward a spring of fresh water."*

Antonie de Saint-Exupéry
<u>The Little Prince</u>

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## PREFACE

The Edwards Aquifer is a prolific source of groundwater within several hydrologically distinct segments along the Balcones Fault Zone in Central and South-Central Texas, from Del Rio on the Mexican border, north to Salado in Bell County. Within the middle reaches of the fault zone, the Edwards Aquifer provides the sole municipal supply for the City of San Antonio as well as for other municipalities, military bases, businesses and industry, and ranches and homes. West of the Balcones Fault Zone, extensive unconfined groundwater reservoirs supply small towns and ranches across the vast expanses of the Edwards Plateau. Similar water-table hydrologic systems provide water for domestic, public, and livestock needs across the Washita Prairie of North-Central Texas.

Within the City of Austin, the Edwards Aquifer comprises examples of both shallow, unconfined, water-table systems on uplands of the Jollyville Plateau, and artesian systems along the Balcones Escarpment. The Barton Springs segment is typical of aquifer segments along the Balcones Fault Zone, in that it is compartmentalized by displacement of water-bearing strata against less-permeable rock units both to the east and west. Also, although much smaller than the San Antonio segment, it nevertheless stores and transmits copious volumes of water from southwest to northeast along the main fault trends. The main natural discharge point for this aquifer segment is Barton Springs, the fourth-largest spring system in Texas. Barton Springs supply a popular City swimming pool, and they possess enormous appeal to the citizenry of Austin. Spring outflow indirectly contributes to part of the City's drinking water supply--that is, spring discharge mixes with Town Lake (Colorado River) and is taken up by Green Water Treatment Plant on the north side of the lake. The Green Plant supplies about 20 percent of the City's potable water. The Barton Springs segment supplies water for several small towns and thousands of individual wells in southwestern Travis County and northern-most Hays County; it is managed by a local groundwater conservation district. The Jollyville Plateau segment is physically separate from the Barton Springs segment, and its importance as a water supply is only minor. However, it possesses certain important ecological attributes, sustaining springs and associated mesic environments along the plateau edges. Also, in providing base flow to creeks draining the Jollyville Plateau, it indirectly contributes to Lake Austin, the City's major source of drinking water. Farther north and east of the Balcones fault line, the Jollyville Plateau segment of the aquifer merges with the Northern Edwards Aquifer, which supplies water to Round Rock and Georgetown, and several important springs in Williamson and Bell Counties.

The Edwards Aquifer derives much of its porosity from karst voids that range in scale from fractions of an inch to several ft in diameter. Given such conduits, overall porosity is low (about 1 percent), but permeability is very high. Typical thin soils, large flow conduits, and rapid groundwater transmission provide only minor means for attenuation of contaminants, and local declines in water quality have been documented. Such conditions occurring in a rapidly growing urban center pose numerous scientific, socioeconomic, and political/public administrative issues that involve groundwater hydrology, economic demands on (and uses of) private property, the common weal, and sometimes heated public emotions. Over the years, and especially recently, major political campaigns have been fought over the issues of quality and quantity of discharge from Barton Springs in the face of rapidly growing urban and suburban development.

This field trip includes seven stops (fig. 1). At these stops, we will address some of the scientific issues related to the Edwards Aquifer segments in the Austin area. Stop 1 will provide an overview of geologic and hydrologic issues along the Balcones Escarpment and beyond. Stop 2 will view micro-porosity development in part of the Edwards Aquifer. Stop 3 will view a remarkable spring-limestone grotto complex at the eastern edge of the Bull Creek watershed, which is also adjacent to a densely developed part of northwest Austin. Stop 4 will view springs issuing from the western, and less developed margins of the Bull Creek watershed. At Stop 5, we will have crossed the Colorado River and are viewing soil, landforms, and vadose-zone hydrology of typical Hill Country terrain that makes up the contributing zone, upstream from the recharge zone to the Barton Springs Segment. At Stop 6, we will view the water-quality filtration pond for Barton Creek Mall and discuss the various kinds of structural and nonstructural methods aimed at mitigating pollution of this part of the aquifer. Finally, at Stop 7, we will visit Barton Springs; there we will discuss results of water quality sampling of the springs as well as the problems of documenting sources of pollutants and the preliminary efforts at listing the Barton Springs salamander as an endangered species.

This guidebook includes several short stand-alone papers that address various themes developed during the field trip. After the series of articles, a road log for the trip is presented. This road log is organized as if the starting and ending point of the trip were Barton Springs Pool parking lot in Zilker Park.

We gratefully acknowledge support for this field trip from several sources: Union Texas Petroleum generously subsidized cost of printing the guidebook. Conoco, Inc., Finding Functional Excellence defrayed costs for refreshments. Sylvia Pope assisted David A. Johns with some of the figures and reviewed part of the text. Bob Russell edited parts of this text. Tammy Goforth assisted C.M. Woodruff with his illustrations and with layout of the guidebook. Elizabeth Huebner provided yeoman service in translating text from wildly disparate word-processing software including MacIntosh applications and a cranky and obsolete MS-DOS program that hardly anyone uses.

David A. Johns
C.M. Woodruff, Jr.
Austin, Texas
October 1994


Figure 1. Shaded-relief map of Austin area showing the seven stops that compose the field trip; also shown are the Balcones Escarpment and the Bull Creek watershed (map from U.S. Geological Survey).

# BALCONES FAULT ZONE AND COLORADO RIVER--
# DUAL CONTROLS ON THE EDWARDS AQUIFER NEAR AUSTIN, TEXAS

C.M. Woodruff, Jr.

*"The really fundamental geological elements of Austin are two: the (Colorado) river with its valley and the Balcones fault system."*

Peter T. Flawn

## LOCAL CONDITIONS

With an outstanding economy of words, a single sentence has been employed by Flawn (1990 p. 228) to characterize the key geologic attributes of Austin, Texas. An examination of the subunits of the Edwards Aquifer in the Austin area emphasizes the truth of this statement, as the structural geometry, physiographic setting, and groundwater regimes are dramatically different across the main fault line and on the two sides of the Colorado River. A geologic map of the Austin area (fig. 1) clearly documents the abrupt changes in outcrop geometry of the Edwards Limestone north and south of the Colorado River and east and west of the Mount Bonnell Fault (Garner and Young, 1976). North of the Colorado River, the most areally extensive outcrop of Edwards Limestone lies immediately west of the main fault line. There, this resistant limestone unit caps the Jollyville Plateau and forms a disjunct eastern outlier of the once more continuous Edwards Plateau. This plateau outlier is held up by less than 100 ft of the basal Edwards Limestone. South of the Colorado River, in contrast, the contiguous outcrop of Edwards Limestone occurs east of the Mount Bonnell Fault. There, virtually a complete section of Edwards Limestone is downfaulted against the Glen Rose Limestone on the west side of the fault line. Edwards exposures west of the fault line are limited to isolated hilltops and local ridges, and consist of the bottom twenty ft or so of the 350-ft-thick Edwards section.

North of the Colorado River, beneath the Jollyville Plateau, groundwater occurs in shallow and locally discontinuous horizons under water table conditions. Discharge of groundwater occurs in a distributive manner. That is, water flows out the edges of the relict table land, with spring flow occurring most abundantly where streams breach the edges of the dissected plateau. Elsewhere, ephemeral seeps discharge during wet periods. For much of the Jollyville Plateau terrain, the aquifer host rock is thin, consisting only of the basal few tens or scores of feet, and volumes of water stored and transmitted are perforce limited. Wells drawing on this shallow aquifer are few and are typically shallow and are capable of only low yields. Little concentration of surface flow results in diffuse recharge with the bulk of incident rainfall being cycled back to the atmosphere through the processes of evapotranspiration. Although the limestone host rock progressively thins to the north, in areas east of the main fault line, the Edwards Aquifer becomes thicker than that seen along the edges of the Jollyville Plateau. Given a greater saturated thickness and several streams providing loci of concentrated recharge, the aquifer is a more prolific water producer farther north providing potable supplies for the towns of Pflugerville, Round Rock, and Georgetown and numerous farms and ranges in the area. Locally important springs occur along the main fault line from Georgetown north to Salado and beyond (Yelderman, 1987).

South of the Colorado River, and west of the Mount Bonnell Fault, the entire Edwards section has been removed by erosion across most of this area. There, the "stair-step hills" typical of the Central Texas Hill Country is underlain chiefly by Glen Rose Limestone, and this landscape composes the contributing zone upstream from the main recharge areas of the Barton Springs segment of the aquifer. In this contributing area, little or no hydrologic


Explanation:

Ked-JP -- Edwards Limestone underlying the Jollyville Plateau
Ked-BSS -- Edwards Limestone underlying the Barton Springs Segment

Figure 1. Simplified geologic map of the Austin area showing Edwards Limestone outcrop areas north and south of Colorado River and east and west of the Mount Bonnell Fault (modified from Garner and Young, 1976).

communication of groundwater occurs across the main fault line. Instead, stream flow is channeled to the six major creeks that drain the contributing landscape and convey surface water across the main fault line. There, on the recharge zone, approximately 85 percent of total recharge to the Barton Creek segment of the aquifer occurs within the channels of Onion, Barton, Slaughter, Bear, Little Bear, and Williamson Creeks (Slade and others, 1976). Recharge occurs into the thick, nearly continuous section of karstic limestone, and as the groundwater moves downdip to the east, it becomes confined beneath overlying low-permeability strata and moves under artesian pressure to the northeast to Barton Springs, which is virtually the only natural discharge point for this segment of the aquifer. Thus, in contrast to the distributive, shallow, low-yield aquifer seen on the Jollyville Plateau, the Barton Springs segment of the aquifer is a prolific integrated system channeled to a single natural discharge point.

Explained in context of Flawn's two major geologic controls, the Balcones Fault Zone juxtaposes the entire thickness of the Edwards Limestone against less permeable strata on both the west and the east. Faults and associated fractures also provide initial conduits for groundwater flow, and many of these porous zones became enlarged by dissolution with ongoing positive-feedback as discussed by Abbott (1975), such that initial concentration of groundwater flow enlarged conduits, allowing more water to flow within these conduits, which in turn, resulted in yet further localized dissolution. Overall southwest-to-northeast groundwater flow within the artesian zone moves along the general trend of major faults of the Balcones fault system. The primary natural discharge point, Barton Springs, is situated where it is because of the base level provided by the Colorado River. The artesian flow drains to this topographic low point just as do surface streams.

## REGIONAL CONTEXT/REGIONAL CONTROLS

Viewed in a regional context, the subsections of the Edwards Aquifer noted north and south of the Colorado in the Austin area are merely two subset hydrologic segments of a vast karst limestone system--that collectively make up the many disjunct parts of the Edwards Aquifer (fig. 2). Each subset is denoted by a catchment area in which recharge is received and transmitted to one or more natural discharge points. The most prolific segment occurs along the Balcones Escarpment from Hays County west to Kinney County and supplies water for the City of San Antonio, the largest city in the United States to be supplied solely by groundwater (although recent court challenges suggest that San Antonio may have to augment its use of groundwater with some surface supplies [McKinney, D.C., and Watkins, 1993]). This main (San Antonio) segment is larger and more complex, but in general, it functions similar to the Barton Springs segment: The Balcones Fault Zone localizes the aquifer recharge zone, provides a general southwest-to-northeast porosity and aquifer boundary system along faults, and spring sites are localized at topographically low points along major streams where they cross the Balcones Escarpment (Woodruff and Abbott, 1979, 1986). Similar controls are provided by Balcones faulting and the modern drainage network for the Del Rio/San Felipe Springs segment, which lies along the western part of the Balcones Fault Zone (the aquifer extends into Mexico, but it is not well documented beyond the Rio Grande). Likewise, similar controls occur north of the Barton Springs segment within the northern Balcones segment, which extends from the Colorado River north to the Salado vicinity (although an outlier of the Edwards Plateau, the Jollyville Plateau is considered a sub-segment of a more-inclusive "Northern Edwards Aquifer"). Farther north still, in extensive areas of north-central Texas, studies by Yelderman (1987) document yet other areas in which groundwater is obtained from the Edwards Limestone and hydrologically associated members of the Georgetown Limestone within the Washita Prairie physiographic region. North and west of the main water-yielding segments along the Balcones Escarpment is the vast Edwards Plateau, which is in hydrologic communication with the underlying Trinity Group aquifer, and thus is considered by Texas water agencies as the "Edwards-Trinity aquifer" (Texas Water Development Board, 1991). This unconfined aquifer system is controlled by the topography of the Edwards Plateau, whose margin is sculpted by streams cutting into the plateau edges.

As stated at the outset, the two major controlling factors on the geology (hence, on groundwater) in the Austin area are the Balcones fault system and the Colorado River. The dual influences of Balcones fault geometry, and surface drainage evolution on recharge/discharge geometry has been noted by Woodruff and Abbott (1979) within the San Antonio segment of the Edwards Aquifer; similar controls have been noted for the Barton Springs segment, as well (Woodruff, 1984; Woodruff and Abbott, 1986). Stream piracy along the Balcones Escarpment diverted major streams, thereby providing concentrated surface flow, which resulted in deep valley incision within the downfaulted Edwards Limestone. This incision also provided the topographically low points that acted as "drains" for pent-up groundwater; in this way, major spring sites were established where streams cross major faults.

Drainage-basin evolution has also affected the hydrologic attributes of the Jollyville Plateau and of the contiguous Edwards Plateau. The implications of the Jollyville Plateau as an outlying remnant of the Edwards Plateau have been presented by Woodruff (1985, 1987, 1990). A brief review of regional drainage evolution as it has influenced the plateau uplands of Central Texas is presented here.

In the vicinity of the Balcones Escarpment, the Colorado River system appears to be enlarging its drainage basin at the expense of the Brazos watershed. There, the Colorado River exhibits a constricted watershed, and the main stem of the river lies as little as 5.5 straight-line miles from the Brazos/Colorado divide at the margin of the Bull Creek basin. The upper reaches of Bull Creek were once almost certainly part of the Brazos watershed, but the creek was captured by high-gradient streams flowing to the nearby base level provided by the Colorado River. In contrast, the main trunk stream of the Brazos River crosses the Balcones Fault Zone approximately 100 straight-line miles to the north, so that streams within this part of the Brazos watershed typically exhibit low stream gradients. Thus, given its location along a major divide, the Jollyville Plateau is maintained as an upland remnant and an unconfined shallow karst aquifer. With much of its bedrock section draining to springs around the edge of the Bull Creek watershed, this outlying water-table aquifer segment has been drained of most of its saturated thickness, and as a result, vadose-zone caves are abundant and extensive. Because of these widespread caves, the Jollyville plateau contains prime habitat for air-breathing troglobytic arthropods, 5 of which are currently listed as Endangered Species by the U.S. Fish and Wildlife Survey (U.S. Government Printing Office, 1988).

In a broader (state-wide) context, all but one of the main tributaries of Colorado River west of the Balcones Escarpment flow from west to east, thereby entering the river from the south (fig. 3). Thus, the Concho River system, as well as the San Saba, Llano, and Pedernales Rivers, all drain the southwestern part of the upper Colorado River basin. The headwaters of these streams are all fed by the Edwards-Trinity aquifer from the margins of the Edwards Plateau: erosion by these headwaters (as well as subsurface sapping of the plateau by groundwater) mark the edge of the physiographic plateau. The overall geometry of drainage nets west of the Balcones Escarpment suggests that, over the long term, the Colorado River is expanding its watershed at the expense of the southern part of the Brazos watershed. Thus, the Jollyville Plateau is not only a relict upland, but in the long-term of geologic time, it is being dissected relatively quickly, owing to the progressive encroachment of the Colorado watershed at the expense of the Brazos. The occurrence of the Jollyville Plateau as a relict

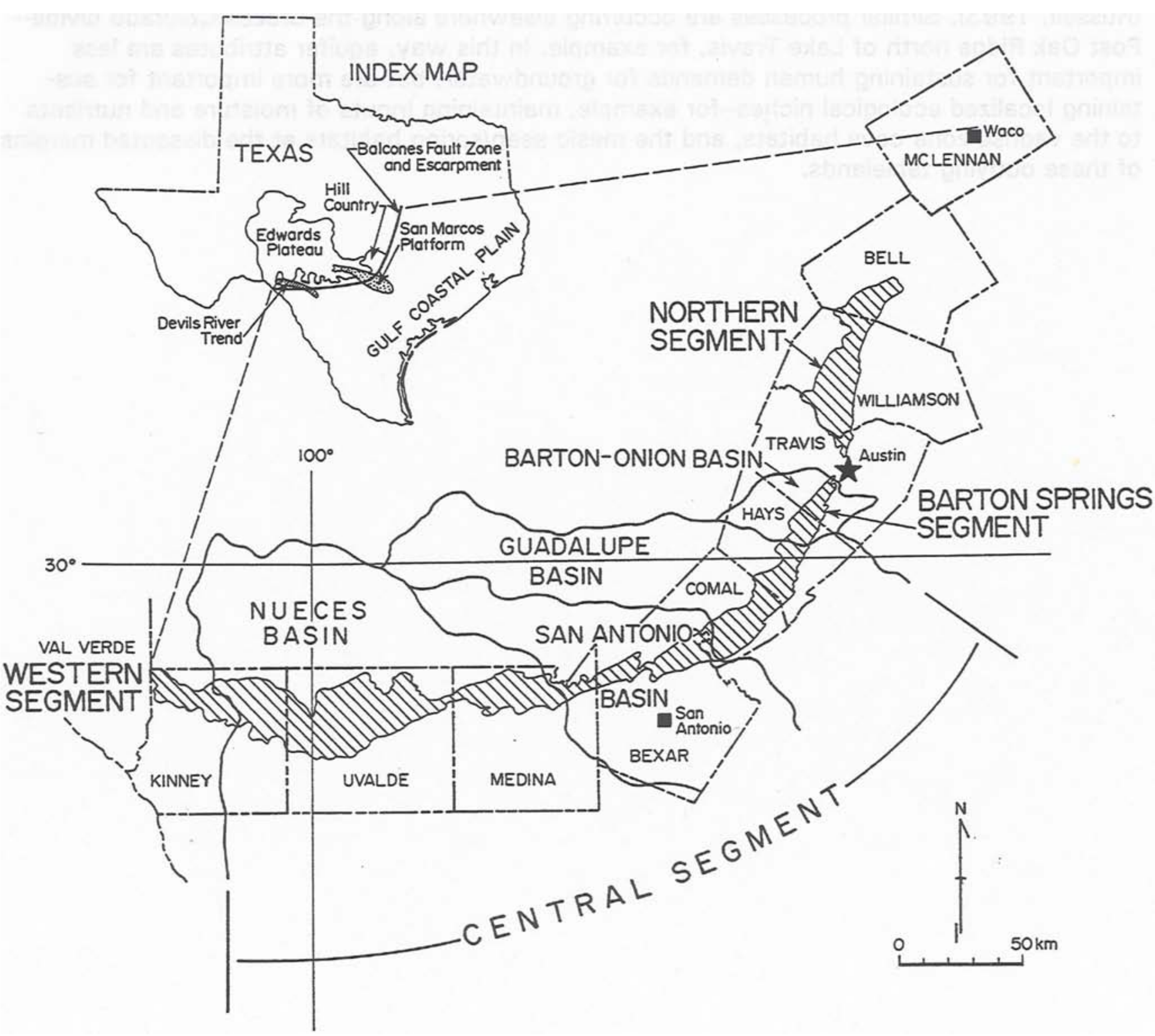
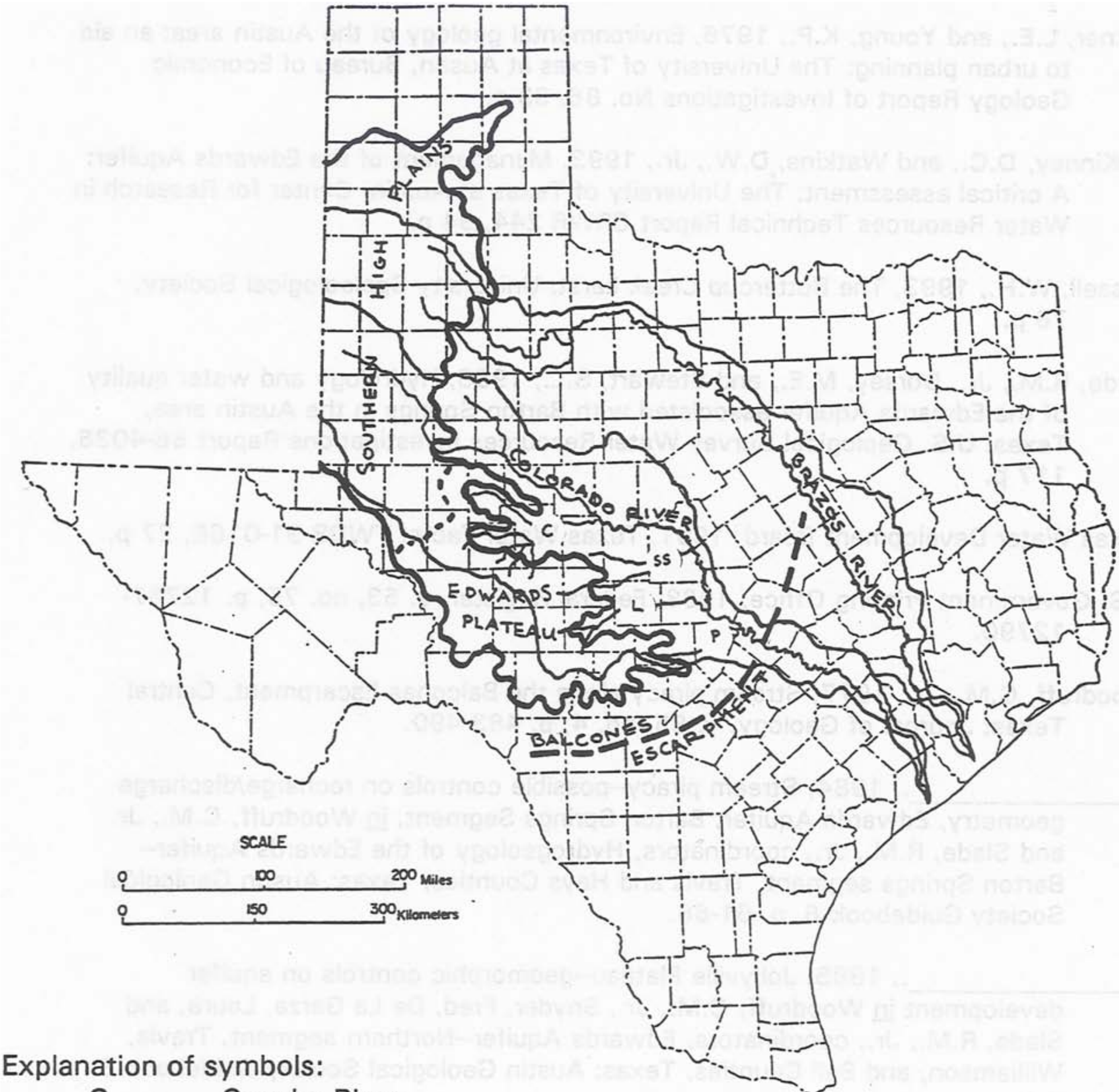



Figure 2. Region-wide map showing major groundwater-bearing segments of the Edwards Limestone (from Woodruff and Abbott, 1986).

upland is a local example of long-term regional landscape evolution, which involves possible structural control of drainage-basin evolution, dissection of a resistant limestone caprock, and chemical sapping of plateau uplands through dissolution by groundwater.

In summary, the Jollyville Plateau is being aggressively dissected on its southern edge, and it is likely being sapped by groundwater dissolution from within, and in fact, there is evidence for ongoing stream piracy via underground diversions of water within karst features connecting Buttercup Creek (within the Brazos watershed) with the Bull Creek system (Russell, 1993). Similar processes are occurring elsewhere along the Brazos/Colorado divide--Post Oak Ridge north of Lake Travis, for example. In this way, aquifer attributes are less important for sustaining human demands for groundwater, but are more important for sustaining localized ecological niches--for example, maintaining inputs of moisture and nutrients to the vadose-zone cave habitats, and the mesic seep/spring habitats at the dissected margins of these outlying tablelands.




Explanation of symbols:

- C -- Concho River
- SS -- San Saba River
- L -- Llano River
- P -- Pedernales River

Figure 3. Statewide view of generalized Colorado River drainage network and major tributaries showing west-to-east extension of sub-basin network compared to Brazos watershed and main stem of the Brazos.

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# ATOP MOUNT BONNELL, A VIEW FROM THE BORDERLAND[1]

C.M. Woodruff, Jr.

*"Upon my soul, Williamson, this must be the very spot where Satan took our Savior to show and tempt him with the riches of this world."*

General Sam Houston to Judge R.M. Williamson, atop Mount Bonnell (c. 1839)

Mount Bonnell stands at the brink of the Balcones Escarpment, which marks the boundary between two of the grand physiographic divisions of North America (Hill, 1896-1897; Fenneman, 1931): The Great Plains Province extends west to the Rocky Mountains, and north into Alberta. The Coastal Plain Province extends east and north along the lowlands bordering the Gulf and Atlantic shorelands. In few other places in North America are major physiographic boundaries so dramatically expressed (fig. 1).

The elevation at the top of Mount Bonnell is 785 ft above sea level. Lake Austin lies below at an approximate level of 483 ft. Although Mount Bonnell is not the highest point within the City of Austin, this dramatic vista overlooks the inner edge of the Gulf Coastal Plain to the east and the dissected margin of the Edwards Plateau to the west. White-rock and Blackland Prairies make up the terrain to the east. Isolated remnants of flat-topped table lands are all that remain of the once-continuous plateau terrain to the west. The Edwards Limestone caprock has been breached all along the edge of the escarpment, and numerous streams have sculpted steep slopes and "stair-step hills" typical of the Central Texas Hill Country. Mount Bonnell is an excellent example of a Hill Country promontory whose topographic relief attests to the former extent of the high-standing Edwards Plateau.

The Balcones Escarpment is a discontinuous topographic rise, a line of hills that generally faces east and forms both a barrier to access from below and an area of overlook from above. Hence, this landform derived its name collectively from a plural Spanish noun, "los balcònes" (the balconies). This multifaceted topographic break extends through Central Texas along an arcuate trend from Del Rio on the Mexican border, through San Antonio, Austin, and north to the vicinity of Waco.

The topographic break that marks the Balcones Escarpment (and hence the view from this promontory) is a response to abrupt geologic changes, the surface expression of which is the juxtaposition of Cretaceous bedrock units across the Balcones Fault Zone. The fault zone, in turn, is controlled by the deformed, eroded, and subsided roots of the Ouachita Mountains that underlie Cretaceous sedimentary rocks about 2,000 ft below Mount Bonnell (Flawn and others, 1961). This basement complex, which extends from Oklahoma through Central Texas to the Rio Grande and from there into Trans Pecos Texas, forms a tectonic hinge that separates the stable continental interior of North America from the still-subsiding Gulf Coast Basin (fig. 2). Periodic adjustments across this hinge zone controlled the location and magnitude of Balcones faulting. The arcuate shape of the fault zone and the coastward-protruding escarpment in this part of Central Texas reflect the underlying structural salient where the Ouachita belt bends around the Llano Precambrian massif. The Balcones Fault Zone is aligned along an overall northeast-southwest orientation, generally parallel to the Ouachita structural trend. In detail, however, local small-displacement faults are oriented in various directions (see Rodda and others, 1970).

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[1] This article is modified from a stop description prepared for a field trip accompanying the Fall, 1993, National Meeting of the Association of Engineering Geologists.

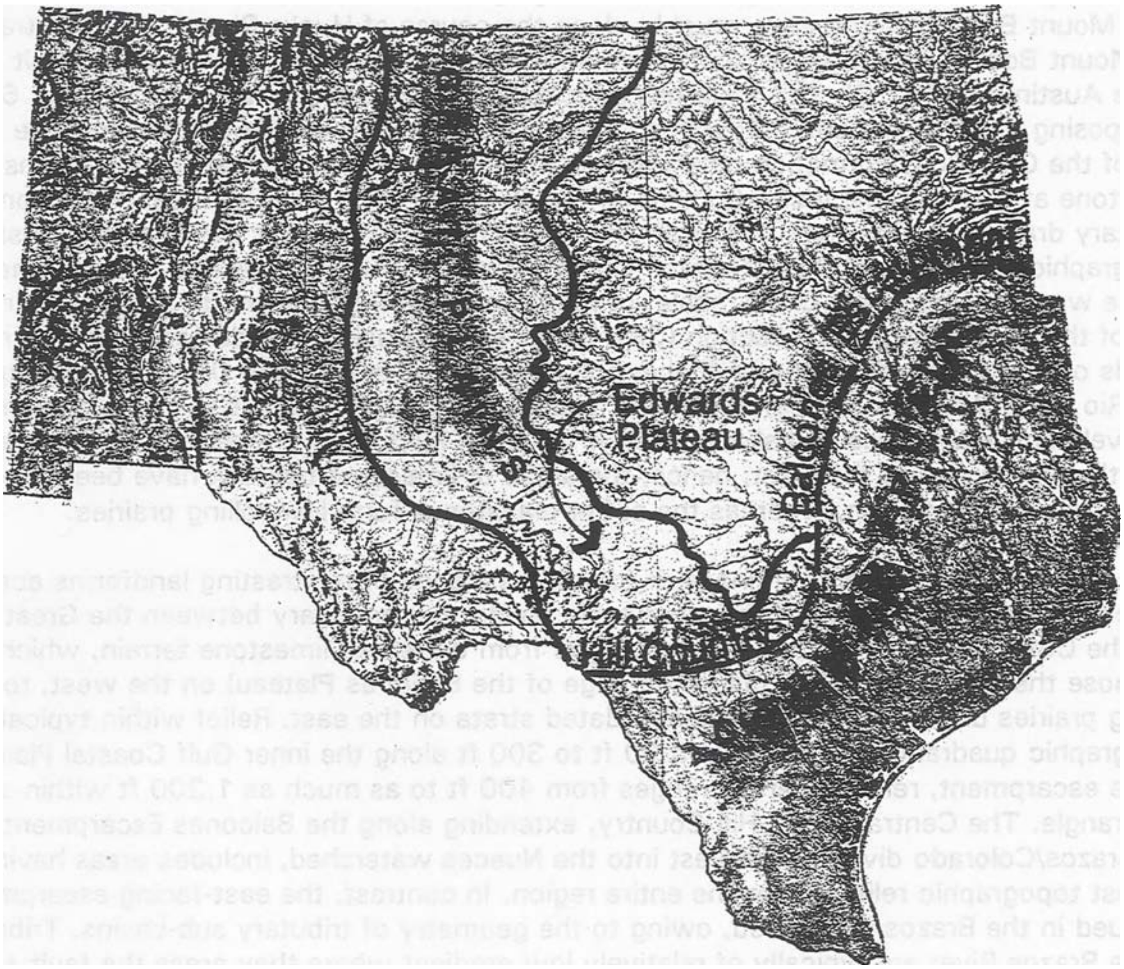



Figure 1. Regional physiography: Balcones Escarpment, Great Plains, and Gulf Coastal Plain (modified from U.S. Geological Survey, National Atlas of the United States).

The main episode of faulting along the Balcones trend occurred during the late Early Miocene (Young, 1972), which is generally contemporaneous with the pervasive uplift and crustal extension associated with Basin and Range mountain-building episodes in Western North America. The Balcones Fault Zone thus marks a possible eastern boundary for this realm of major Cenozoic extensional tectonics. In this way, the fault line and associated escarpment mark a geologic edge between western and eastern tectonic processes (crustal extension in the west versus Gulf Coast subsidence to the east).

Total displacement across the fault zone in Travis County is at least several thousand feet, and individual faults have displacements of up to 1,000 ft. However, many faults composing the system have displacements ranging from a few feet to tens of feet. Downslope from Mount Bonnell to the east, roughly along the course of Hucks Slough, lies the trace of the Mount Bonnell Fault, which is one of the major components of the Balcones Fault System in the Austin area (fig. 3). This fault has a local stratigraphic displacement of almost 600 ft, transposing virtually the entire Edwards Limestone downward on the east against the lower half of the Glen Rose Formation on the west. Although limestone is transposed against limestone at this site, the incised course of the Colorado River and the deep dissection of tributary drainage to the river has given rise to the dramatic relief at this site. The customary topographic break across the main fault line is a result of the juxtaposition of hard limestone on the west against softer chalk, shale, or marl to the east. Farther north in the Austin area, part of the lower Cretaceous section (Glen Rose, Walnut, and Edwards Limestone Formations) stands on the west side of the fault line, juxtaposed against selected Upper Cretaceous units (Del Rio Clay, Buda Limestone, Eagle Ford Shale, and Austin Chalk) to the east. In sum, the relatively soft claystones and shales east of the main fault line have been eroded more rapidly than the limestones to the west; hence, the areas of limestone bedrock have been sculpted into a rugged hilly terrain, whereas the softer claystones form low rolling prairies.

The Brazos/Colorado drainage divide marks a zone of contrasting landforms across the Balcones Fault Zone. South of this river basin divide, the boundary between the Great Plains and the Coastal Plain is marked by the change from dissected limestone terrain, which compose the Hill Country (the dissected edge of the Edwards Plateau) on the west, to low rolling prairies underlain by poorly consolidated strata on the east. Relief within typical topographic quadrangles change from 50 ft to 300 ft along the inner Gulf Coastal Plain. West of the escarpment, relief generally ranges from 400 ft to as much as 1,200 ft within a typical quadrangle. The Central Texas Hill Country, extending along the Balcones Escarpment from the Brazos/Colorado divide southwest into the Nueces watershed, includes areas having the highest topographic relief within the entire region. In contrast, the east-facing escarpment is subdued in the Brazos watershed, owing to the geometry of tributary sub-basins. Tributaries to the Brazos River are typically of relatively low gradient where they cross the fault zone, reflecting generally minor displacement across faults and long distances to confluences with the main stream of the Brazos. More subdued relief in the Brazos watershed is reflected by different physiographic provinces denoted west of the fault line: there, the area west of the escarpment composes the Lampasas Cut Plain and the Washita Prairie. The Colorado River, in contrast, provides a topographically low base level near the drainage divide that separates the Brazos River Basin from that of the Colorado. Steep tributaries to the Colorado River erode rapidly and thereby progressively capture marginal headwaters within the Brazos watershed. Stream piracy is a major process contributing to the evolution of the Edwards aquifer all along the Balcones Escarpment (Woodruff, 1977, 1984; Woodruff and Abbott, 1979, 1986). The escarpment is a hydrologic borderland: surface water processes change abruptly with the changes in terrain, and groundwater availability varies markedly across the fault zone.

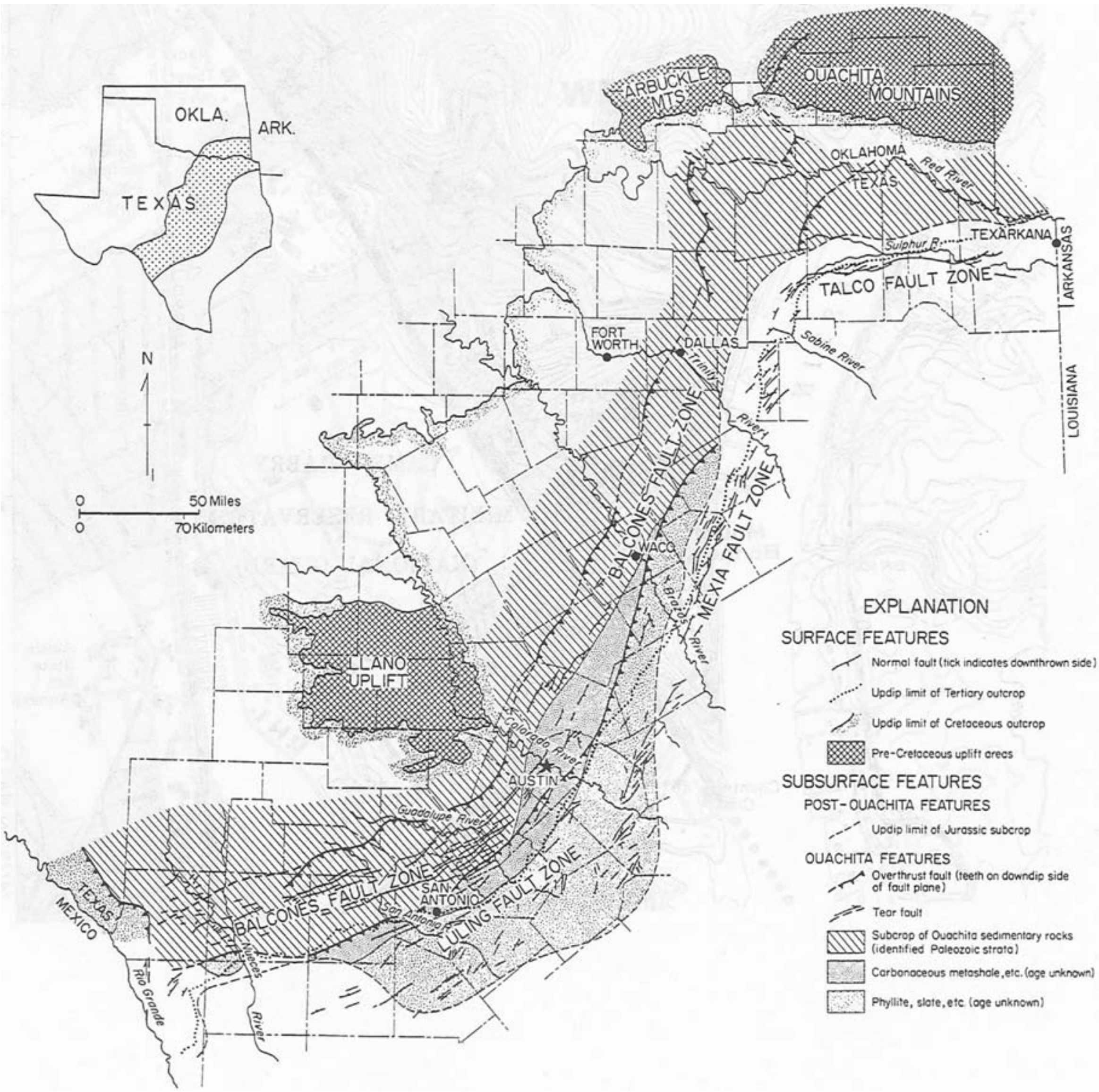
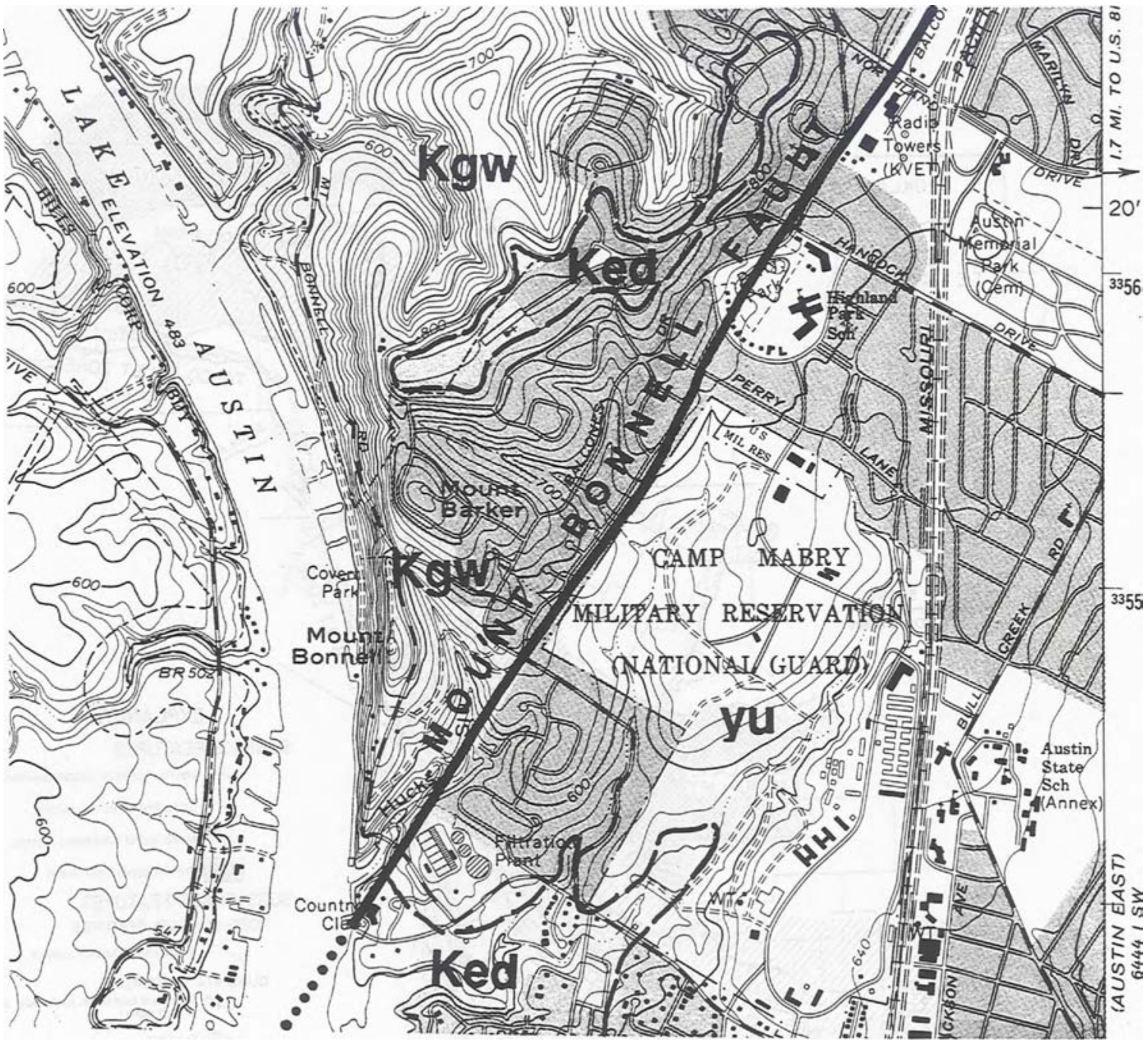



Figure 2. Structural/Tectonic features along the Balcones/Ouachita Trend, Central Texas (from Woodruff and McBride, 1979).




Explanation:

| | | |
|---|---|---|
| yu | -- | complex area of faulted units younger than Edwards Limestone |
| Ked | -- | Edwards Limestone |
| Kgw | -- | Glen Rose and Walnut Formations (units older than Edwards Limestone) |

Figure 3. Geologic and landform changes across the Mt. Bonnell Fault in the vicinity of Mt. Bonnell (modified from Rodda and others, 1970).

The Balcones Fault Zone and Escarpment continue to exert profound influences on human endeavors. In detail, faulting has created a mosaic of different rock types that results in varying local ground conditions with resulting variations in engineering properties. In addition to topographic changes across the fault line, the Balcones Escarpment marks a dividing line in terms of soils, plant and animal associations, climate and surface and subsurface water regimes, and human uses of the land. For example, the area along the Balcones Escarpment is a zone of climatic hazard: it is the area of highest probability of large, flood-producing storms in the country (Hoyt and Langbein, 1955). Although of generally modest relief, the escarpment is the first topographic barrier inland from the Gulf of Mexico, and there, unstable, moisture-laden Gulf air masses are forced to rise. In so doing, they cool and produce phenomenal storms. In September, 1921, more than 38 inches of rain fell in a 24 hour period near the Blackland community of Thrall in Williamson County. This compares to a usual annual rainfall rate in Austin of about 32 inches. Other storms have produced record rainfall rates for shorter periods of time. The D'Hanis Flood of 1935 (Medina County) resulted from 22 inches of rain in 2 hours and 45 minutes (Baker 1975). In short, the Hill Country is especially prone to flash flooding, owing to the coincidence of extreme rates of rainfall, steep slopes, and a large number of small, high-gradient streams. Extreme precipitation events, in turn, provide positive feedback to geomorphic systems: High-magnitude rains provide the means for rapid erosion, channel incision, and downstream sedimentation, all of which generally contribute to severity of future flood events, which further intensify processes of erosion, sedimentation, and the like.

In summary, Mount Bonnell marks a site overlooking the Balcones Escarpment, formed owing to different rates of erosion across the Balcones Fault Zone with its abrupt bedrock changes and its underlying control by the buried Ouachita structural complex. These ancient, deep-seated structural dislocations continue to dramatically affect almost all other attributes of the land: terrain, soils, vegetation and animal habitat, surface-water and groundwater availability, weather, and all water-related processes. The geologic break thus marks an ecological borderland occurring at the juncture between the coastal prairies, and the plains to the west.

These environmental changes also have interacted to impose profound effects on human endeavors across the fault zone. A cultural borderland coincides with the geological/ecological discontinuity. The occupants of the coastal prairies have a southern (eastern) orientation; farming is the dominant agrarian land use. The Hill Country/Edwards Plateau, in contrast, has a cultural heritage based on scant water, grasslands, and livestock production (Webb, 1931; Rose, 1990). The physical fault zone coincides with the "institutional fault" proposed by Walter Prescott Webb in his accounting for the influence of aridity on the attempts by settlers at coping with the environments of the Great Plains (Webb, 1931). The Balcones Escarpment separates the cotton culture of the Old South from the rangelands and the cattle economy of the Old West (Bybee, 1952; Flawn, 1964). This borderland has long been a preferred site for human settlements, because changes in the natural environment allow people to draw on natural resources from both east and west and from the two main underpinnings of the respective economies: cotton and cattle (Palmer, 1986). In brief, the Balcones Escarpment marks the beginning of the American West in terms both of ecology and human destiny.

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# GROUNDWATER QUALITY IN THE BULL CREEK BASIN, AUSTIN, TEXAS

David A. Johns

## INTRODUCTION

Growth in the Austin metropolitan area into the Hill Country west of town has raised questions of the effects of urbanization on groundwater quality. Water quality in watersheds west of Austin is important because these drainage systems contribute to the drinking water supply for the city. Austin currently has three water treatment plants: two on Lake Austin near Tom Miller Dam and one on Town Lake. Shallow groundwater systems supply base flow to these creeks through springs and seeps which, in turn, contribute flow to the Colorado River. The effects of urbanization on these shallow systems is unclear, but potential problems from even moderately polluted base flow are numerous and far reaching, ranging from declining aquatic life to more expensive water treatment processes. Increasing impervious cover also will reduce recharge and thus decrease base flow in these watersheds.

The Bull Creek watershed is located at the eastern edge of the Texas Hill Country and immediately west of the Balcones Fault Zone. Rough cultural boundaries are U.S. Highway 183, RM 620, RR 2222, and Loop 360. The watershed has a surface drainage area of about 32 mi$^2$ (or about 20,000 acres) and flows into Lake Austin, a constant level impoundment on the Colorado River. The watershed is characterized by flat plateau uplands incised by numerous steep-sided canyons. Creek systems are elongate to the west and north with only short, steep tributaries draining uplands on the east side of the watershed, adjacent to the Balcones Escarpment. Total relief in the Bull Creek Basin is about 600 feet, with upland elevations ranging from 900 feet on the east and north sides up to 1100 feet on the west side. Typical relief from the uplands to channels is about 200 feet in the upper creek reaches and greater in lower reaches.

The Bull Creek watershed is ideal for evaluating impacts of urbanization on groundwater systems. Development has yet to reach all parts of the watershed, and identical geologic and geomorphic setting across the basin allows for comparison of groundwater parameters to characterize developed and undeveloped recharge areas. Because Edwards Limestone underlies the upland margin of the Bull Creek watershed, examining springs in Bull Creek provides insights into urban impacts on karst hydrologic systems. These data may be critical to protecting groundwater quality in other areas underlain by the Edwards where effects of local activities are masked by regional flow patterns, complex flow paths, and by larger volumes of groundwater.

## HYDROGEOLOGY

Geologic units cropping out within the Bull Creek watershed area include the Cretaceous-age Glen Rose Formation, the Walnut Formation, the Comanche Peak Formation, Edwards Formation, and Quaternary-age Terrace and Alluvial sediments (Garner and Young, 1976; Rodda and others, 1970). Delineation of the stratigraphy in the northern portion of the basin is complicated by facies changes in the carbonate strata. Member 1 of the Edwards Formation occupies the upland plateau areas, consisting of porous, interbedded limestone and dolomite that make up the basal part of the Edwards. Macro- and microkarst solution features are common and include bedding plane cavities and vertical pipes. Water catchment for individual features may be minor when considered alone, but subsurface integration of karst conduits focuses groundwater movement to discharge areas at canyon heads. The Comanche Peak Formation consists of soft, nodular limestone and generally occurs at or near the base of the

Edwards and occurs in the lower upland areas or as ledges in the upper reaches of tributaries on the north side of the watershed. Three members of the Walnut Formation (or two depending on whether the Cedar Park Limestone is included in the Edwards or in the Walnut Formation) are exposed in the watershed. It consists of an upper marly, soft limestone (Bee Cave Member) and a lower hard dense limestone (Bull Creek Member). They generally form steep slopes with local benches below the plateau uplands. The upper four members of the Glen Rose are exposed in the watershed and generally form the canyon slopes and valley floors. These members consist of interbedded hard and soft marly limestone which forms stair-stepped topography common to parts of the Hill Country. Quaternary Terrace deposits are paleochannel deposits preserved adjacent to the main channels of Bull and West Bull Creeks, predominantly in the areas along Loop 360 and RR 2222. They consist of poorly consolidated, tan gravel, sand, silt, and clay. Quaternary alluvial sediments consist of unconsolidated gravel, sand, and silt deposited in the present channel and flood plains of the creeks.

Three hydrogeologic systems are active in the Bull Creek watershed; the Edwards-Walnut, the Glen Rose, and the Quaternary systems. There is no estimate of the relative contribution of springs from each system to the total flow in Bull Creek. In general terms, Edwards-Walnut springs are likely more critical to upper creek reaches, Glen Rose springs more important in middle and lower reaches, and Quaternary springs are only locally important. The Edwards-Walnut and Glen Rose springs are the chief water sources in the unique canyon head areas and upper creek reaches where the Jollyville Plateau salamander occurs. The Jollyville Plateau salamander is a rare species that may be added to the Endangered Species List in the future by the U.S. Fish and Wildlife Service.

The Edwards-Walnut hydrogeologic systems include springs discharging from massive, vuggy limestone at the heads of creeks and tributaries. Typically these discharge sites are characterized by rimrock canyon heads (cliff-like near vertical walls) forming small grottos, often with associated shelter caves which can be spectacular archeological sites. These sheltered sites contain lush mesic vegetation and are in sharp contrast to drier vegetation of the upland terrain. Recharge to these springs is only from direct infiltration of rain water on the Edwards-capped upland plateau and what storm water can infiltrate in the short swales and draws before channels drop into the steep canyons leading to the basin floor. Focused recharge occurs locally where sinkholes capture runoff during heavy rains. However, recharge may not be confined to the topographically defined surface watershed. Russell (1993) suggests that some water may recharge spring systems on the northwest side of the basin through major cave passages from the Buttercup Creek area two miles north.

The Glen Rose hydrogeologic systems generally discharge at springs along creek channels, although specific discharge points can be difficult to recognize owing to alluvial sediment cover and existing surface flow. Large springs can create beautiful maidenhair fern banks along channels, for example near the end of Old Lampassas Trail and in Bull Creek Park. Additional examples of Glen Rose groundwater systems are visible in road cuts along Loop 360 south of the RR 2222 intersection, where broad travertine drapes highlight groundwater discharge from porous horizons, and beautiful frozen waterfalls can form during freezing weather. Recharge to Glen Rose springs is likely from the Lake Travis area, as well as from seepage from the overlying Edwards-Walnut system, and direct infiltration of rainfall - all with possible contribution from the Buttercup Creek area (Russell, 1993).

Terrace and alluvial springs tend to be ephemeral because of their limited storage capacity. They may be locally recharged from direct infiltration of rainfall or recharged from Glen Rose springs discharging into the sediments. Alluvial springs can also be recharged during floods as water inundates flood plains. An excellent example of a terrace spring can be seen along Loop 360 immediately south of RR 2222 where a road cut intercepted the groundwater flow path through a paleochannel perched high above the existing channel of West Bull Creek.

## METHODS

Two data sets were analyzed to characterize groundwater quality in the Bull Creek watershed: those of the United States Geological Survey (USGS) and results from samples collected by City of Austin (COA) staff studying water quality in the Bull Creek watershed (City of Austin, 1993). See Figure 1 for locations of springs in each data set.

Since 1987, as part of a cooperative agreement between the City of Austin and the USGS, water has been collected from wells and springs in the Northern Edwards Aquifer in the Austin area (the part of the aquifer north of the Colorado River). Three of these springs are in the Bull Creek watershed: Stillhouse Hollow, Tanglewood, and Schlumberger. Stillhouse Hollow is in an area that has been developed for over 25 years. Tanglewood is also in a urban setting, but the development is younger by 10-15 years. Schlumberger is in a low density development setting with a research campus and septic irrigation field possibly in its recharge area. Samples are collected following at least 7-to-10 days without rain (<0.1 inches) to eliminate possible short-term storm water effects. Data from June 1987 to June 1992 were available for analysis.

The second groundwater data set is from a 1993 water quality study that included springs specifically identified to characterize groundwater in the Bull Creek watershed. Because the watershed contains both developed and undeveloped land, an opportunity existed to characterize impacts of urbanization on groundwater quality. To classify each sampled spring, an assumption was made that the recharge area was relatively close to the spring, at least within the surface drainage area. A spring with residential, commercial, or industrial development within a likely recharge area was considered to be influenced by that development and, therefore, was not considered pristine. Based on this assumption, five springs in developed areas and five springs in undeveloped areas were selected and sampled. All 1993 COA spring samples were collected within a three day period in August under dry conditions; no significant rain had fallen for several weeks prior to sampling. In fact some springs initially targeted for sampling had too little flow to collect samples for use in this study.

## RESULTS

Results from COA spring samples were grouped according to the land use, developed or undeveloped, so that statistical tests could be applied to the data. The USGS data base for the three springs in the Bull Creek watershed contained a sufficient number of data points that statistical tests could be run on data from each spring, rather than groups of springs, for comparison.

Statistical tests on both data sets reveal a number of significantly different results in water chemistry between developed and undeveloped springs in the Bull Creek Watershed (Table 1). Specifically, the results indicate that concentrations of most major dissolved ions (Ca, Na, K, SO4, Cl), nitrate-nitrogen ($NO_3$-N), nickel, and total organic carbon (TOC) are higher in developed areas that in undeveloped areas. Chemical parameters related to the dissolved mineral content in water (hardness, specific conductivity, total dissolved solids, and alkalinity)

Figure 1


LEGEND

— — Creeks and Tributaries

G1 City of Austin Sampling Site

USGS 1 USGS Sampling Site

SCALE

0 1 2 MILES

N

**BULL CREEK SPRING SAMPLING SITES**

Base Map: "Recharge Zone of the Northern Edwards Aquifer Near Austin, Texas" by Garza and Slagle, City of Austin, 1988.

also reflect these results. Median values for statistically significant parameters from developed springs are from 1.6 to 6 times greater than undeveloped springs.

Springs G2 and G3 consistently had the highest concentrations of most parameters (Figures 2, 3, 4, and 5), whereas spring G9 usually had the lowest concentrations of the developed sites. Of the undeveloped springs, G4 generally had the highest concentrations; lowest concentrations were not associated with any one spring.

Organophosphate pesticides (which include diazinon and malathion) were tested for but not detected in COA samples with detection limits ranging from 0.5 to 2.5 ug/l. Heavy metals, except nickel, were not consistently detected which the exception of the common metals zinc, manganese, iron, and barium. Nickel is present in most samples but in significantly higher concentrations in developed springs. Factors affecting the presence of nickel in developed springs are not known.

The extensive USGS data base identified more parameters with significantly different results than the limited COA data base. The three Bull Creek springs in the USGS data show distinct differences between each spring and also between the two springs with developed recharge areas, Stillhouse Hollow and Tanglewood, and the less developed Schlumberger spring (Table 2). Stillhouse Hollow and Tanglewood consistently have the highest concentrations of the parameters with significantly different results - with the exception of $NO_3+NO_2$-N. Stillhouse spring has far greater $NO_3+NO_2$-N concentrations than either of the other two springs, and Schlumberger has higher significantly different concentrations than Tanglewood. Generally, Stillhouse Hollow had the highest concentrations for all parameters in the USGS data base. Figures 6, 7, 8, and 9 illustrate these differences between sites. Results from the USGS data support results of the COA study.

## INTERPRETATION

Attempting to determine what factors of development cause the water quality differences in the spring sampling is problematic. A variety of different development factors likely contribute to cause the observed results. Most developments adjacent to springs are residential (mostly single-family) and were not designed or constructed under strict water quality ordinances, and most do not have water quality ponds. The oldest subdivisions are in the eastern part of the watershed, and so water quality problems associated with development density, lack of water quality controls, or infrastructure deterioration might be evident first in springs in this area. Additional factors possibly contributing to chemistry of the groundwater include type of development (i.e. single-family residential, multi-family residential, commercial), density of development, type of wastewater service (central or on-site {septic}), type of wastewater lines, proximity of development to springs, residence time of water in the aquifer, and lithology of aquifer.

The increase in concentration of major ions in groundwater in developed areas could be a result of numerous factors. One reason for their increase may be due to reduced recharge because of impervious cover. Less rain water infiltration could effectively increase the concentration of constituents normally present in groundwater. If this is true, there may be a correlation between the amount of impervious cover in the recharge area and the increase in ion concentration over normal (undeveloped) conditions. Since there are no historical flow records for these springs, it will be difficult to determine if spring discharge has been affected by development. Decreased rainwater infiltration may reduce the groundwater gradient, resulting in diminished spring flow and increase residence time of water in the aquifer. Prolonging the time groundwater is in contact with the limestone host rock would increase the

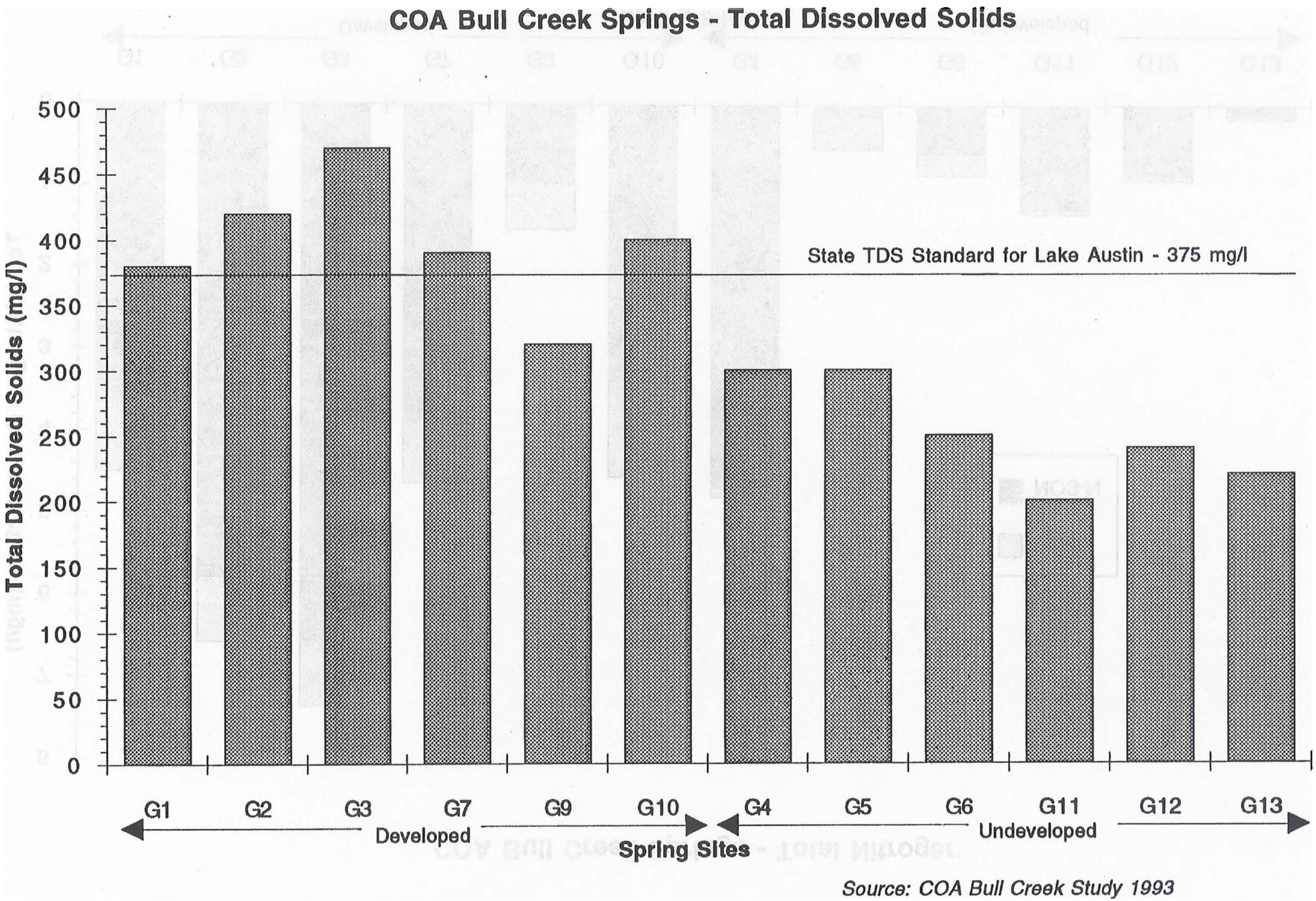


Figure 2. Total dissolved solids for Bull Creek springs from City of Austin 1993 data.

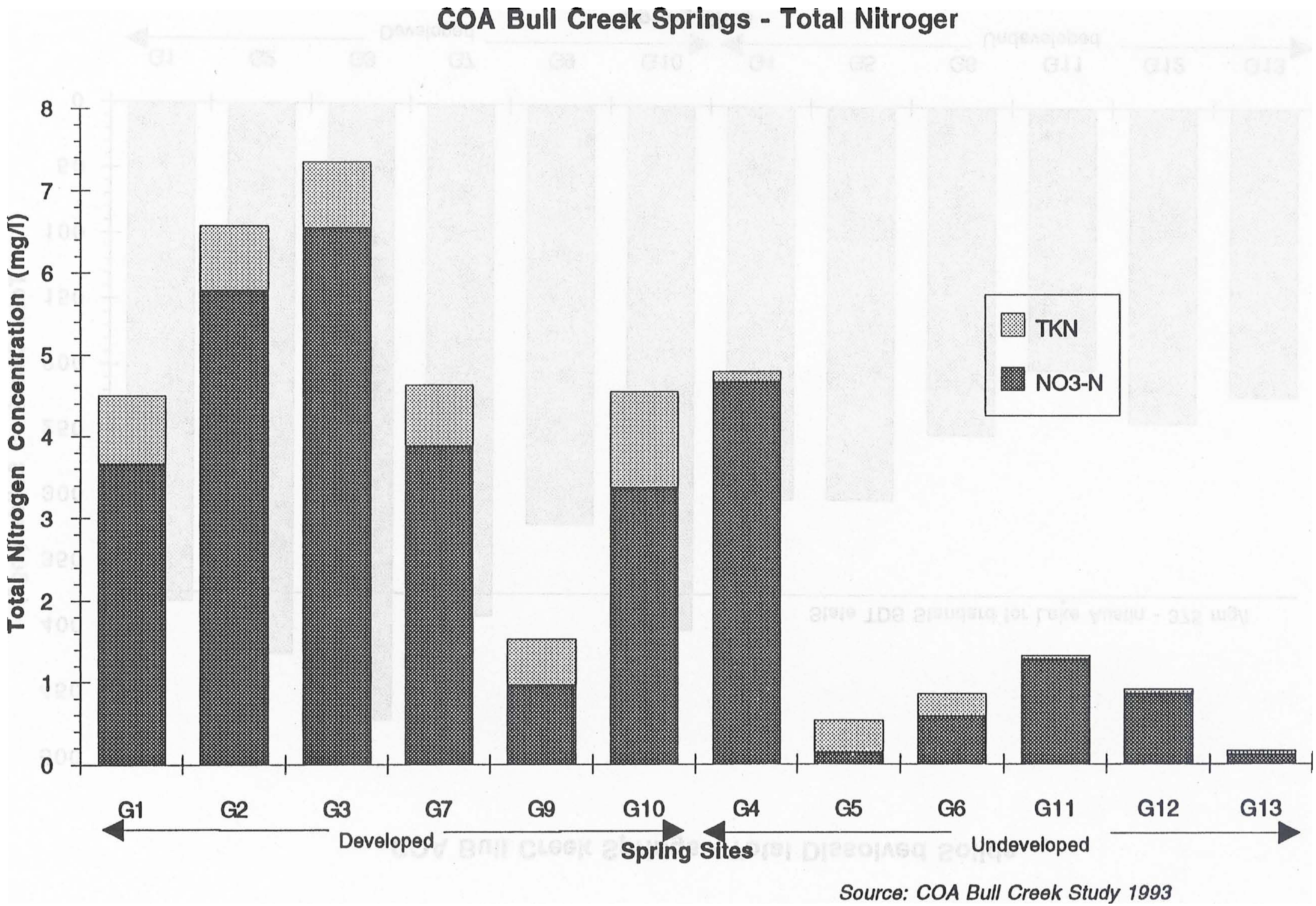


Figure 3. Total nitrogen for Bull Creek springs from City of Austin 1993 data.

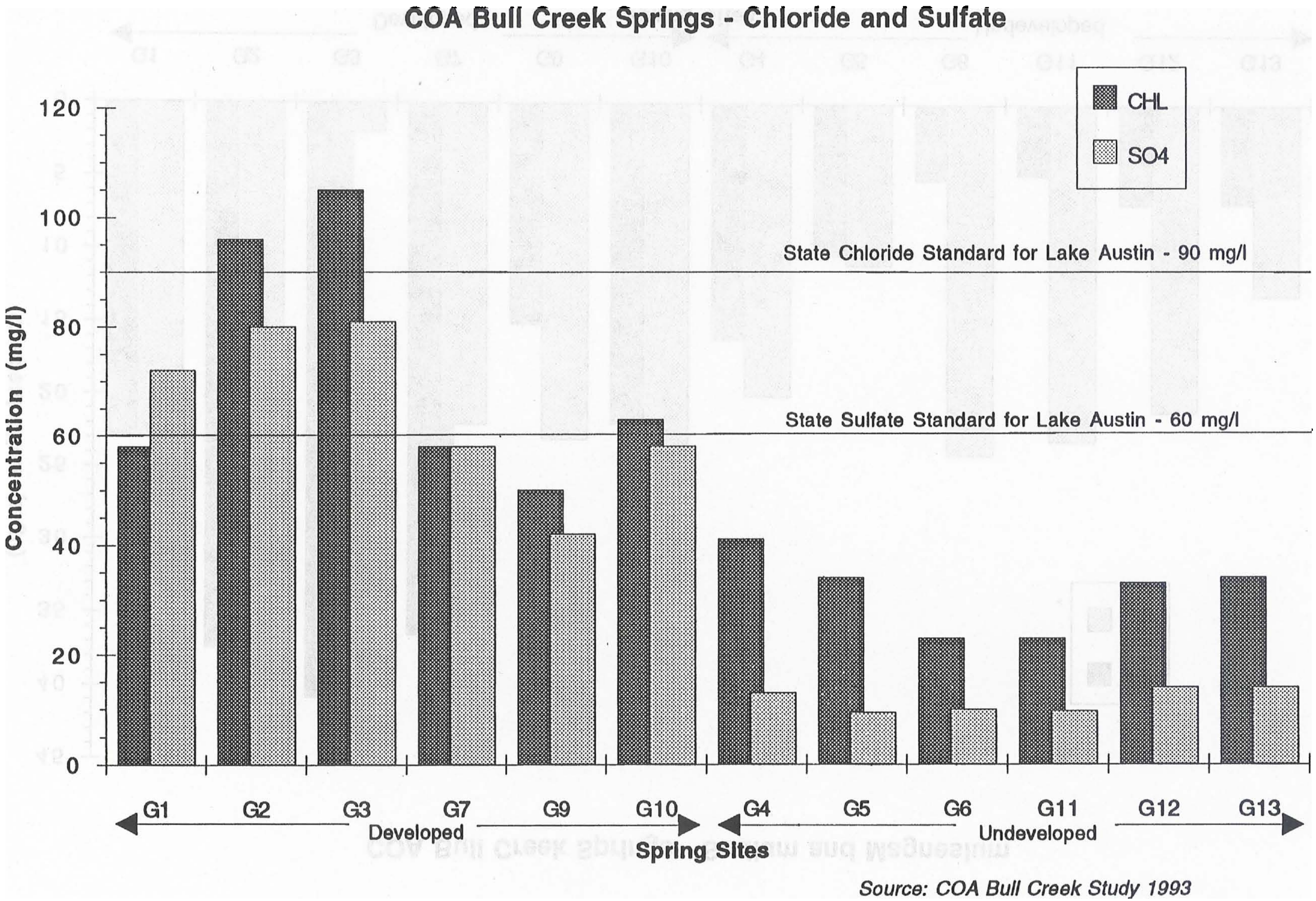


Figure 4. Chloride and sulfate for Bull Creek Springs from City of Austin 1993 data.

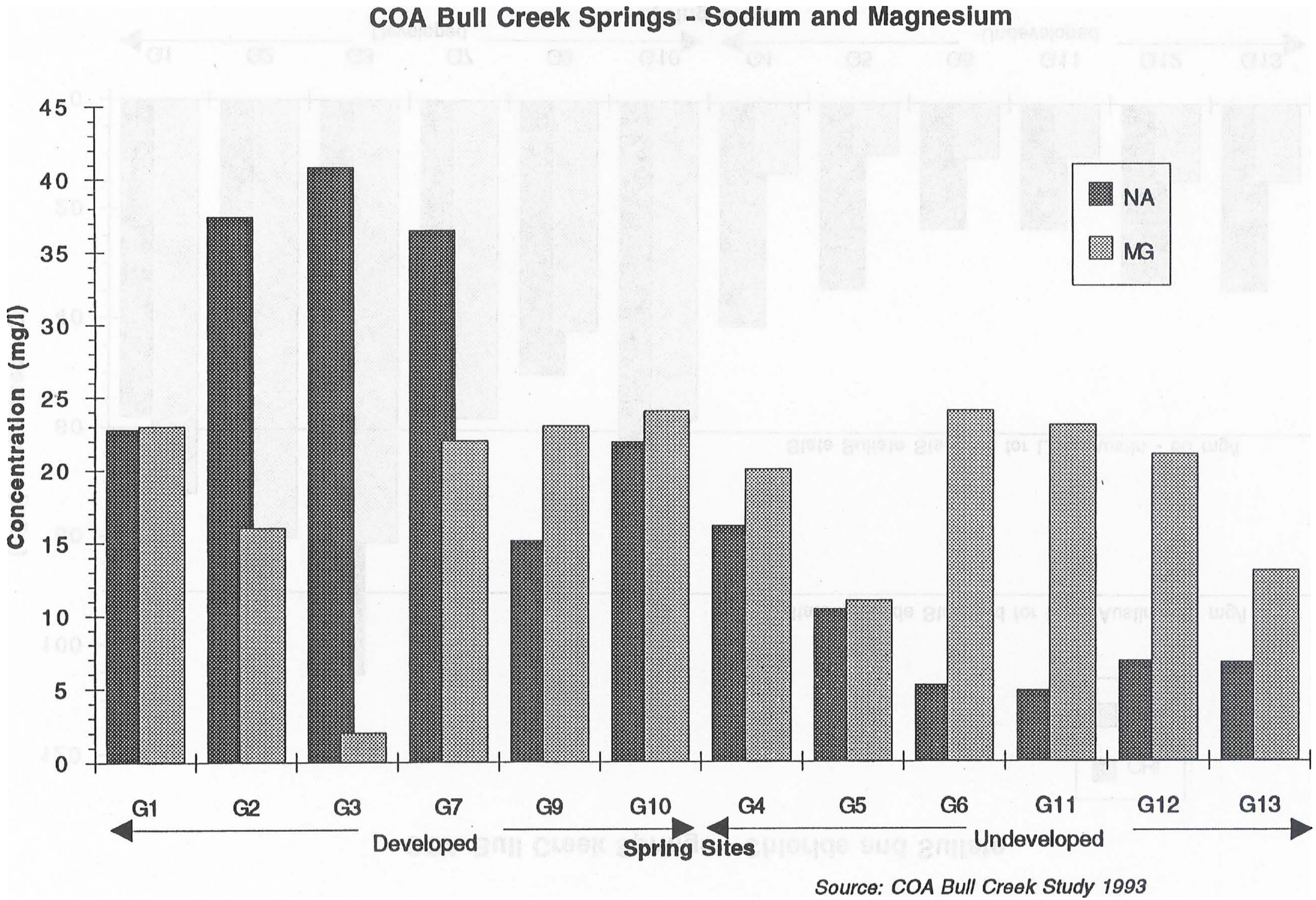


Figure 5. Sodium and magnesium for Bull Creek springs from City of Austin 1993 data.

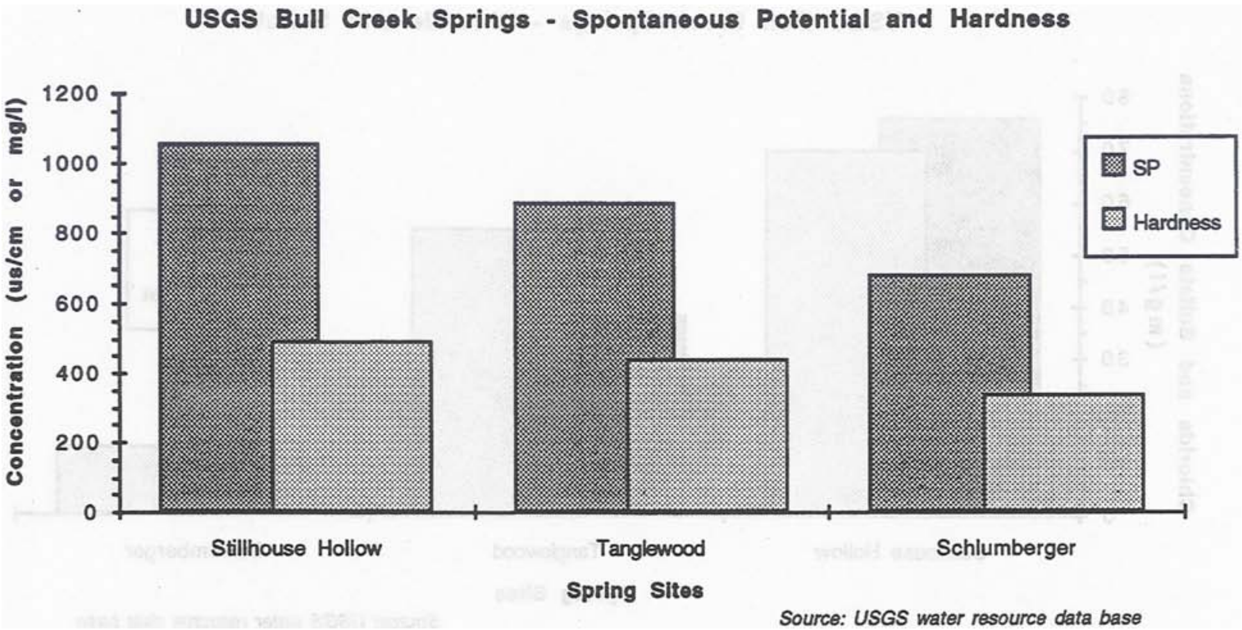


Figure 6. Spontaneous potential and hardness from USGS Bull Creek spring data.

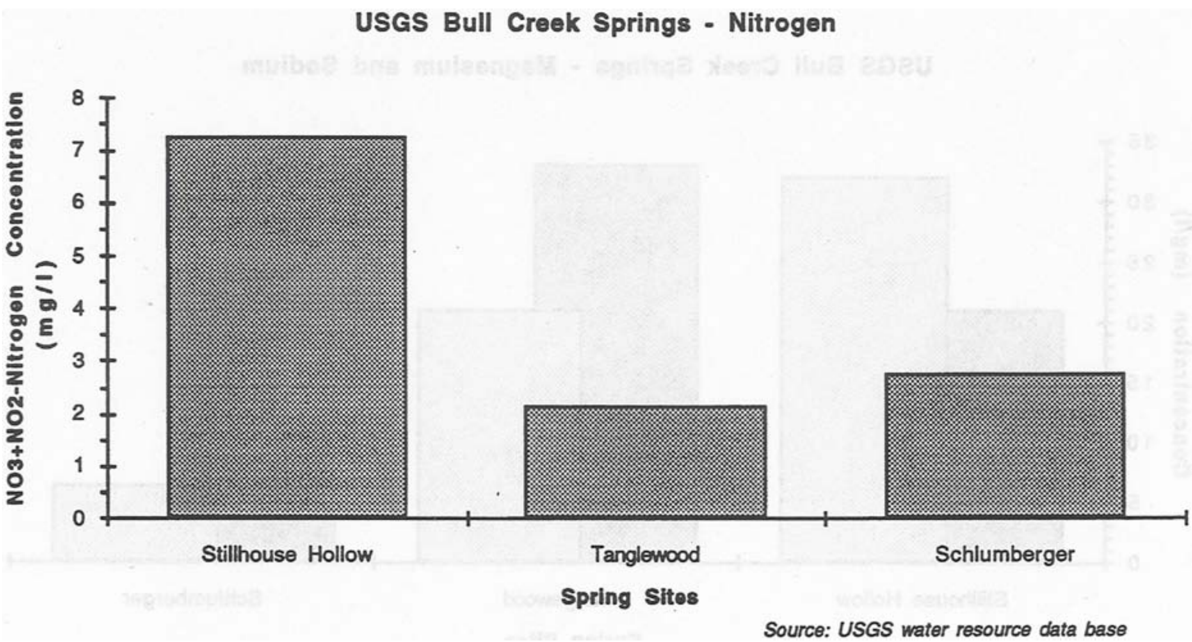


Figure 7. Nitrogen from USGS Bull Creek springs data.

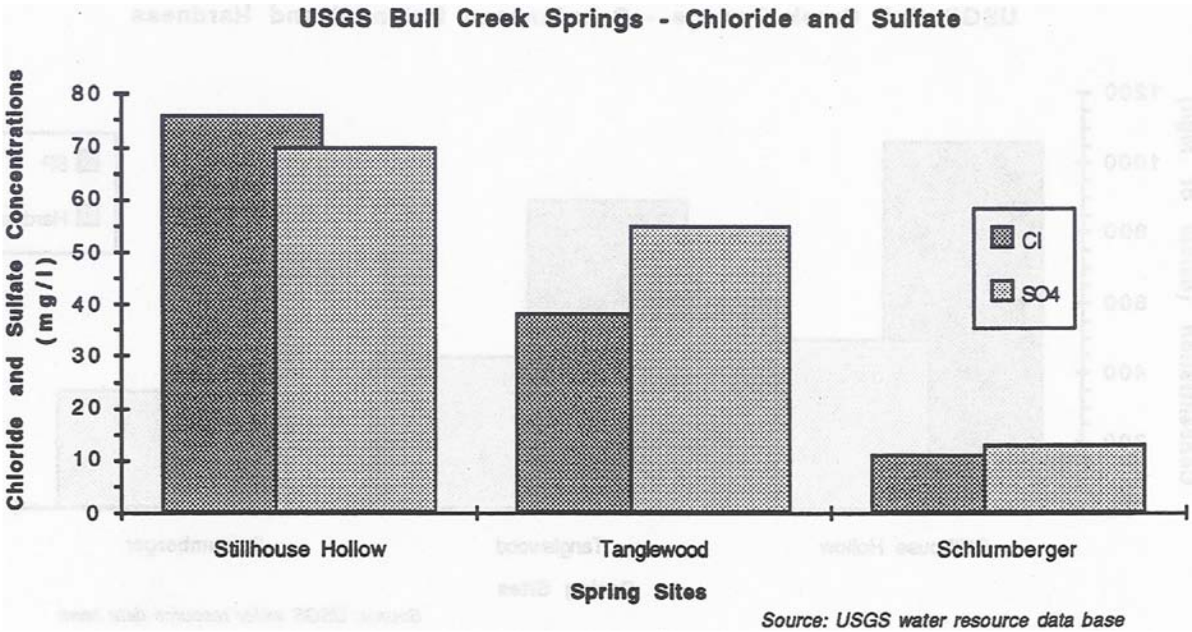


Figure 8. Chloride and sulfate from USGS Bull Creek spring data.

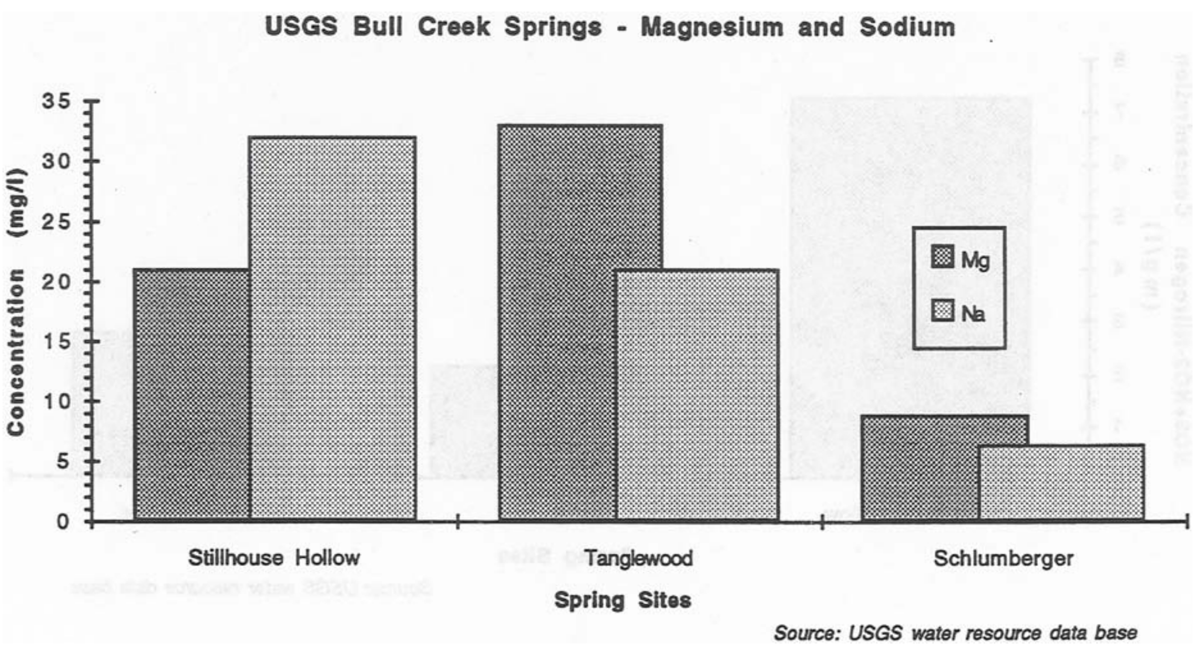


Figure 9. Magnesium and sodium from USGS Bull Creek springs data.

Table 1. City of Austin 1993 Bull Creek spring data.

| SITE | DATE | AQUIFER | TEMP | PH | TSS | TDS | NO3-N | TKN | NH3-N | TP | ORTHO-P | TOC | CHL | SO4 | F | K | NA | MG | CA | ALK | IMP C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | | | 10x | | | | | | | | | | | | | | | % |
| **DEVELOPED** | | | | | | | | | | | | | | | | | | | | | |
| G1 | 8/16/93 | Kgr | 27 | 7.3 | <0.5 | 380 | 3.66 | 0.84 | 0.02 | 0.02 | <0.02 | 1.15 | 58 | 72 | 0.26 | 2.13 | 22.8 | 23 | 141 | 365 | 16.4 |
| G2 | 8/16/93 | Ked | 23 | 7.4 | 0.5 | 420 | 5.78 | 0.79 | 0.02 | 0.02 | <0.02 | 1.34 | 96 | 80 | 0.14 | 0.90 | 37.4 | 16 | 172 | 295 | 26.2 |
| G3 | 8/16/93 | Ked | 23.5 | 7.5 | <0.5 | 470 | 6.54 | 0.81 | 0.02 | 0.02 | 0.02 | 1.22 | 105 | 81 | 0.1 | 0.96 | 40.8 | 2 | 190 | 343 | 26.2 |
| G7 | 8/17/93 | Ked | 24 | 7.5 | 1.2 | 390 | 3.88 | 0.75 | 0.03 | <0.02 | <0.02 | 3.05 | 58 | 58 | 0.14 | 1.15 | 36.5 | 22 | 150 | 386 | 28.6 |
| G9 | 8/17/93 | Ked | 24 | 7.1 | <0.5 | 320 | 0.96 | 0.57 | 0.03 | 0.02 | <0.02 | 4.55 | 50 | 42 | 0.46 | 0.82 | 15.1 | 23 | 132 | 370 | 16.4 |
| G10 | 8/18/93 | Ked | 26 | 7.5 | <0.5 | 400 | 3.37 | 1.17 | 0.03 | <0.02 | <0.02 | 3.2 | 63 | 58 | 0.23 | 1.39 | 21.9 | 24 | 139 | 379 | 25.9 |
| | | | | | | | | | | | | | | | | | | | | | |
| Median | | | 24 | 7.5 | | 395 | 3.77 | 0.80 | 0.03 | | | 2.2 | 60.5 | 65 | 0.19 | 1.06 | 29.7 | 23 | 146 | 368 | |
| Average | | | 24.6 | 7.4 | | 397 | 4.03 | 0.82 | 0.03 | | | 2.42 | 71.7 | 65.2 | 0.22 | 1.23 | 29.1 | 18 | 154 | 356 | |
| | | | | | | | | | | | | | | | | | | | | | |
| **UNDEVELOPED** | | | | | | | | | | | | | | | | | | | | | |
| G4 | 8/17/93 | Ked | 23.5 | 7.5 | <0.5 | 300 | 4.66 | 0.13 | 0.04 | 0.02 | <0.02 | 2.08 | 41 | 13 | 0.24 | 0.70 | 16.1 | 20 | 109 | 322 | 5.1/11.6 |
| G5 | 8/17/93 | Ked | 24 | 8 | <0.5 | 300 | 0.14 | 0.39 | 0.05 | <0.02 | <0.02 | 1.84 | 34 | 9.4 | 0.15 | 0.56 | 10.4 | 11 | 126 | 322 | 8.2 |
| G6 | 8/17/93 | Ked | 23.5 | 7.5 | <0.5 | 250 | 0.58 | 0.27 | 0.03 | <0.02 | <0.02 | 2.01 | 23 | 9.9 | 0.11 | 0.32 | 5.2 | 24 | 136 | 310 | 5 |
| G11 | 8/18/93 | Kwa | 23 | 7.3 | 1.4 | 200 | 1.27 | 0.05 | 0.02 | <0.02 | <0.02 | 3.67 | 23 | 9.7 | 0.15 | <0.10 | 4.8 | 23 | 93 | 310 | 5 |
| G12 | 8/18/93 | Ked | 22 | 7.2 | <0.5 | 240 | 0.85 | 0.05 | 0.02 | <0.02 | <0.02 | 14? | 33 | 14 | 0.15 | 0.34 | 6.8 | 21 | 111 | 343 | 5 |
| G13 | 8/18/93 | Kgr/Alluv | 23.5 | 7.5 | <0.5 | 220 | 0.11 | 0.05 | 0.02 | 0.02 | <0.02 | 1.72 | 34 | 14 | 0.14 | 0.39 | 6.7 | 13 | 95 | 281 | 5 |
| | | | | | | | | | | | | | | | | | | | | | |
| Median | | | 23.5 | 7.5 | | 245 | 0.715 | 0.09 | 0.03 | | | 2.01 | 33.5 | 11.5 | 0.15 | 0.39 | 6.75 | 21 | 110 | 316 | |
| Average | | | 23.3 | 7.5 | | 252 | 1.27 | 0.16 | 0.03 | | | 2.26 | 31.3 | 11.7 | 0.16 | 0.46 | 8.33 | 19 | 112 | 315 | |
| | | | | | | | | | | | | | | | | | | | | | |
| Units are parts per million | | | | | | | | | | | | | | | | | | | | | |
| Organophosphate Pesticides were not detected | | | | | | | | | | | | | | | | | | | | | |
| Medians calculated by using one-half of detection limit for 'less than' values | | | | | | | | | | | | | | | | | | | | | |
| Highlighted parameters indicate results that are significantly different. | | | | | | | | | | | | | | | | | | | | | |

*Source: COA Bull Creek Study 1993*

Table 1 (cont.)

| SITE | DATE | AQUIFER | O/G | TPH | Cu | Zn | Ni | Cd | Mn | Mo | Fe | Hg | As | Ba | Pb | Cr | Be | Ag | Se | Sb | Tl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | |
| DEVELOPED | | | | | | | | | | | | | | | | | | | | | |
| BIC-G1 | 8/16/93 | Kgr | 5 | <5 | 6 | 37 | 22 | 6 | <1 | <10 | <5 | <0.2 | <1 | 0.08 | <2 | <8 | <1 | 1 | <2 | <3 | <1 |
| BIC-G2 | 8/16/93 | Ked | <5 | <5 | <3 | <2 | 32 | <1 | <1 | <10 | <5 | <0.2 | <1 | 0.1 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G3 | 8/16/93 | Ked | <5 | <5 | <3 | 3 | 52 | <1 | <1 | <10 | <5 | <0.2 | 2 | 0.14 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G7 | 8/17/93 | Ked | <5 | <5 | <3 | 2 | 35 | <1 | <1 | <10 | 11 | <0.2 | <1 | 0.09 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G9 | 8/17/93 | Ked | <5 | <5 | <3 | <2 | 28 | <1 | 2 | 21 | <5 | 0.3 | <1 | 0.1 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G10 | 8/18/93 | Ked | <5 | <5 | <3 | <2 | 3 | <1 | 1 | <10 | 8 | <0.2 | <1 | 0.14 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| | | | | | | | | | | | | | | | | | | | | | |
| Median | | | | | | | 30 | | | | | | | | | | | | | | |
| Average | | | | | | | 29 | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| UNDEVELOPED | | | | | | | | | | | | | | | | | | | | | |
| BIC-G4 | 8/17/93 | Ked | <5 | <5 | <3 | 3 | <3 | <1 | <1 | <10 | <5 | <0.2 | <1 | 0.12 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G5 | 8/17/93 | Ked | <5 | <5 | <3 | <2 | <3 | <1 | 46 | <10 | 65 | <0.2 | <1 | 0.06 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G6 | 8/17/93 | Ked | <5 | <5 | <3 | 2 | 5 | <1 | <1 | <10 | 6 | <0.2 | <1 | 0.06 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G11 | 8/18/93 | Kwa | <5 | <5 | 4 | <2 | 5 | <1 | <1 | <10 | <5 | <0.2 | <1 | 0.18 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G12 | 8/18/93 | Ked | <5 | <5 | <3 | <2 | 5 | <1 | 1 | <10 | <5 | <0.2 | <1 | 0.06 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| BIC-G13 | 8/18/93 | Kgr/Alluv | <5 | <5 | <3 | 2 | 5 | <1 | 1 | <10 | <5 | <0.2 | <1 | 0.1 | <2 | <8 | <1 | <1 | <2 | <3 | <1 |
| | | | | | | | | | | | | | | | | | | | | | |
| Median | | | | | | | 5 | | | | | | | | | | | | | | |
| Average | | | | | | | 5 | | | | | | | | | | | | | | |

Units are parts per billion, except O/G and TPH are in parts per million

Organophosphate Pesticides were not detected

Medians calculated by using one-half of detection limit for 'less than' values

Highlighted parameters indicate results that are significantly different.

*Source: COA Bull Creek Study 1993*

Table 2. U.S. Geological Survey Bull Creek spring data.

| | DATE | SP | HARDNESS | NO3+NO2-N | TOC | CA | MG | NA | K | SO4 | CL | F | TDS | NH3-N | ORG-N | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **USGS - 1** | 6/23/87 | 972 | | 6.8 | 1.5 | | | | | | | | | 0.04 | 0.76 | 0.03 |
| STILLHOUSE HOLLOW | 8/20/87 | 1060 | 490 | 7.3 | 0.9 | 160 | 22.0 | 29.0 | 0.7 | 76 | 65 | 0.1 | 581 | 0.03 | 0.97 | 0.01 |
| | 2/23/88 | 1000 | 490 | 6.5 | 0.8 | 160 | 21.0 | 29.0 | 1 | 70 | 70 | 0.2 | 590 | 0.01 | | 0.02 |
| | 5/5/88 | 1060 | | 6.9 | 1.5 | | | | | | | | | 0.03 | 0.27 | 0.02 |
| | 7/12/88 | 1050 | | 7 | 1 | | | | | | | | | 0.02 | 0.18 | 0.01 |
| | 8/8/88 | 1070 | 470 | 7.4 | 1.1 | 150 | 22.0 | 29.0 | 0.7 | 68 | 70 | 0.1 | 564 | 0.02 | 0.78 | 0.02 |
| | 2/22/89 | 998 | 490 | 5.9 | 0.8 | 160 | 21.0 | 32.0 | 1 | 70 | 76 | 0.1 | 579 | 0.04 | 1.3 | 0.03 |
| | 5/8/89 | 1060 | | 6.8 | 1.4 | | | | | | | | | 0.05 | 0.65 | 0.02 |
| | 7/19/89 | 1060 | | 7.5 | 1 | | | | | | | | | 0.03 | 0.37 | 0.02 |
| | 8/22/89 | 1060 | 490 | 6.5 | 1 | 160 | 21.0 | 32.0 | 0.9 | 69 | 78 | 0.1 | 585 | 0.03 | | 0.02 |
| | 2/5/90 | 990 | 490 | 7.2 | 1 | 160 | 23.0 | 33.0 | 1 | 68 | 81 | 0.2 | 588 | 0.01 | | 0.04 |
| | 6/6/90 | 1090 | | 7.7 | 2.1 | | | | | | | | | 0.01 | | 0.01 |
| | 7/24/90 | 1080 | | 7.3 | 1 | | | | | | | | | 0.01 | 0.49 | 0.01 |
| | 8/17/90 | 1080 | 490 | 7.9 | 1.1 | 160 | 22.0 | 34.0 | 0.8 | 78 | 90 | 0.1 | 607 | 0.01 | | 0.02 |
| | 3/6/91 | 1130 | 480 | 8.1 | 1.5 | 160 | 20.0 | 36.0 | 1.2 | 88 | 11 | 0.1 | 622 | 0.01 | 0.69 | 0.02 |
| | 8/7/91 | | | 7.9 | 1 | | | | | | | | | 0.04 | 0.46 | 0.02 |
| | 6/23/92 | 1070 | 500 | | | 170 | 19.0 | 35.0 | 1.1 | 83 | 94 | <0.1 | | 0.02 | | 0.02 |
| | 7/14/92 | | | | | | | | | | | | | | | |
| Median | | 1060 | 490 | 7.25 | 1 | 160 | 21.0 | 32.0 | 1 | 70 | 76 | 0.1 | 587 | 0.02 | 0.65 | 0.02 |
| Average | | 1052 | 488 | 7.17 | 1.2 | 160 | 21.2 | 32.1 | 0.9 | 74 | 70.6 | 0.13 | 590 | 0.02 | 0.63 | 0.02 |

*Source: USGS water resource data base.*

Table 2 (cont.)

| | DATE | SP | HARDNESS | NO3+NO2-N | TOC | CA | MG | NA | K | SO4 | CL | F | TDS | NH3-N | ORG-N | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **USGS - 2** | 6/23/87 | 933 | | 2.2 | 2.5 | | | | | | | | | 0.04 | 0.66 | 0.01 |
| TANGLEWOOD | 8/20/87 | 949 | 460 | 2.3 | 1.7 | 130 | 34.0 | 21.0 | 1.4 | 56 | 37 | 0.2 | 532 | 0.03 | 0.47 | 0.63 |
| | 2/23/88 | 840 | 440 | 2.2 | 1.9 | 120 | 33.0 | 19.0 | 1.5 | 55 | 38 | 0.2 | 496 | 0.01 | | <0.01 |
| | 5/5/88 | 877 | | 2.2 | 2.1 | | | | | | | | | 0.02 | 0.18 | <0.01 |
| | 7/13/88 | 866 | | 1.3 | 2.1 | | | | | | | | | 0.01 | | 0.01 |
| | 8/8/88 | 922 | 440 | 1.6 | 2 | 120 | 33.0 | 21.0 | 1.7 | 47 | 41 | 0.2 | 501 | 0.01 | | <0.01 |
| | 2/22/89 | 808 | 410 | 1.6 | 1.9 | 110 | 32.0 | 19.0 | 1.5 | 52 | 37 | 0.2 | 463 | 0.02 | | <0.01 |
| | 5/3/89 | 889 | | 2 | 1.8 | | | | | | | | | 0.02 | 0.38 | <0.01 |
| | 7/18/89 | 916 | | 2.3 | 1.5 | | | | | | | | | 0.02 | | 0.01 |
| | 8/22/89 | 870 | 440 | 1.7 | 2.1 | 120 | 33.0 | 20.0 | 1.5 | 50 | 37 | 0.2 | 503 | 0.03 | 0.27 | <0.01 |
| | 1/31/90 | 822 | 400 | 1.2 | 1.6 | 110 | 31.0 | 17.0 | 1.6 | 53 | 34 | 0.2 | 461 | 0.01 | | <0.01 |
| | 6/6/90 | 909 | | 2.3 | 2.4 | | | | | | | | | 0.01 | | <0.01 |
| | 7/24/90 | 851 | | 2.1 | 1.5 | | | | | | | | | 0.02 | 0.48 | <0.01 |
| | 8/17/90 | 922 | 460 | 2 | 1.9 | 130 | 33.0 | 23.0 | 1.7 | 66 | 52 | 0.4 | 543 | 0.01 | | <0.01 |
| | 3/6/91 | 361 | 460 | 3.6 | 2.3 | 130 | 32.0 | 26.0 | 1.8 | 73 | 60 | 0.2 | 550 | 0.01 | 0.19 | <0.01 |
| | 8/6/91 | 908 | | 2.4 | 2.4 | | | | | | | | | 0.01 | | <0.01 |
| | 6/23/92 | 897 | 470 | | | 140 | 30.0 | 23.0 | 1.5 | 56 | 45 | <0.1 | | 0.02 | | 0.01 |
| | 7/14/92 | | | | | | | | | | | | | | | |
| Median | | 889 | 440 | 2.15 | 2.0 | 120 | 33.0 | 21.0 | 1.5 | 55 | 38 | 0.2 | 502 | 0.02 | 0.38 | 0.01 |
| Average | | 855 | 442 | 2.06 | 2.0 | 123 | 32.3 | 21.0 | 1.6 | 56 | 42.3 | 0.23 | 506 | 0.0176 | 0.3757 | 0.13 |

*Source: USGS water resource data base.*

Table 2 (cont.)

| | DATE | SP | HARDNESS | NO3+NO2-N | TOC | CA | MG | NA | K | SO4 | CL | F | TDS | NH3-N | ORG-N | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| **USGS - 3** | 6/23/87 | 618 | | 1.5 | 0.8 | | | | | | | | | 0.03 | 0.87 | 0.01 |
| SCHLUMBERGER | 8/20/87 | 686 | 340 | 2.2 | 0.4 | 130 | 9.2 | 6.2 | 0.2 | 13 | 11 | 0.1 | 368 | 0.03 | 0.27 | 0.26 |
| | 2/23/88 | 663 | 360 | 2.6 | 0.2 | 120 | 9.4 | 6.2 | 0.4 | 12 | 11 | 0.2 | 382 | 0.01 | | <0.01 |
| | 5/5/88 | 687 | | 2.9 | 0.9 | | | | | | | | | 0.03 | | <0.01 |
| | 7/12/88 | 685 | | 3 | 0.6 | | | | | | | | | 0.01 | 1.1 | 0.01 |
| | 8/8/88 | 680 | 340 | 2.9 | 0.8 | 120 | 9.7 | 5.9 | 0.3 | 13 | 10 | 0.1 | 369 | 0.01 | | 0.02 |
| | 2/22/89 | 661 | 340 | 2.9 | 0.5 | 110 | 9.3 | 5.9 | 0.4 | 13 | 9 | 0.1 | 363 | 0.03 | 0.27 | <0.01 |
| | 5/8/89 | 667 | | 2.9 | 0.7 | | | | | | | | | 0.04 | 0.26 | <0.01 |
| | 7/19/89 | 672 | | 2.8 | 0.4 | | | | | | | | | 0.02 | | 0.02 |
| | 8/22/89 | 684 | 360 | 2.7 | 0.7 | 120 | 8.8 | 6.3 | 0.3 | 12 | 11 | 0.1 | 379 | 0.03 | 0.27 | <0.01 |
| | 2/5/90 | 680 | 360 | 2.8 | 0.7 | 110 | 8.8 | 7.2 | 0.4 | 13 | 18 | 0.1 | 378 | 0.01 | | <0.01 |
| | 6/6/90 | 708 | | 2.7 | 0.4 | | | | | | | | | 0.01 | | <0.01 |
| | 7/24/90 | 722 | | 2.6 | 0.8 | | | | | | | | | 0.72 | 0.68 | 0.04 |
| | 8/17/90 | 717 | 360 | 2.8 | 1 | 130 | 8.9 | 11 | 0.4 | 23 | 30 | 0.2 | 404 | 0.01 | | <0.01 |
| | 3/6/91 | 693 | 330 | 2.1 | 0.6 | 130 | 8.2 | 11 | 0.4 | 15 | 24 | 0.1 | 376 | 0.01 | 0.19 | <0.01 |
| | 8/7/91 | 680 | | 2.2 | 0.9 | | | | | | | | | 0.01 | | 0.01 |
| | 6/23/92 | 617 | 330 | | | 140 | 8.2 | 6.3 | 0.3 | 14 | 11 | 0.1 | | | | |
| | 7/14/92 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Median | | 680 | 340 | 2.75 | 0.7 | 120 | 8.9 | 6.3 | 0.4 | 13 | 11 | 0.1 | 377 | 0.015 | 0.27 | 0.02 |
| Average | | 678 | 347 | 2.6 | 0.7 | 123 | 8.9 | 7.3 | 0.3 | 14 | 15 | 0.12 | 377 | 0.0631 | 0.4888 | 0.05 |

*Source: USGS water resource data base.*

concentration of ions in the water presumably derived from chemical reactions with the host rock (Ca, Mg, $HCO_3$).

The increase in major ions present in springs in developed areas could result from a number of human activities. Heavy irrigation of turf lawns over thin soils could exceed normal rainfall amounts and so increase the amount of soil water percolating downward through the unsaturated zone. Perhaps this practice increases dissolution of limestone, thereby increasing the concentration of ions present in groundwater. Another possibility is that water from over-irrigation migrates through the unsaturated zone more slowly, actually dissolving more limestone because it is in contact with the rock longer than rapid infiltration that occurs during heavy rains. Wastewater also has high concentrations of major ions, so chronic wastewater leaks are potential sources of urban contamination. This scenario suggests that older subdivisions would be more likely to have chronic wastewater line problems because of their age, and, therefore, springs in these area would also have higher ion concentrations, which appears to be true in the available data sets.

Higher nitrate-nitrogen concentrations in developed areas is likely due to fertilizer application on turf lawns. Nitrogen is very mobile and can be easily leached from soils. It is not known if excessive lawn watering and downward migrating soil water play a role in higher nitrogen levels in developed springs. Another source of nitrate in developed areas could be from leaking wastewater lines and oxidation of ammonia present in sewage in the water table aquifer.

The increase in total organic carbon in developed areas, as indicated in the USGS data, could be due to improper storage and disposal of hydrocarbons, roadway runoff, or leaking wastewater lines. Analysis for oil and grease and total petroleum hydrocarbons (TPH) did not eliminate petroleum products as a factor in the TOC increase owing to the high detection limit in the oil and grease and TPH tests (higher than for TOC).

These brainstorming possibilities for contamination are unproven at this time but suggest a variety of ways urban land use could affect groundwater quality.

Although results generally followed expected relationships between developed and undeveloped recharge areas, some springs had surprising results, results which illustrate the difficulty of predicting recharge areas and flow paths in karst terrain. For example, spring G4 is located in an undeveloped setting but commonly had chemical concentrations more similar to developed sites. Although there is no development close to the spring, there are numerous small businesses and a large research campus along RR 2222 closer to RR 620. It appears that water discharging from spring G4 is being affected by development in the 2222/620 area.

Age also appears to be a factor affecting water quality in springs in developed areas. The oldest urbanized areas on the east side of the watershed (built about 25 years ago) are in the recharge areas of springs G2 and G3, which routinely have the highest concentrations of constituents. Spring G9 is in an area developed only within the past 10-15 years, yet it consistently has the highest concentrations of contaminants in the developed springs.

## CONCLUSIONS

Groundwater samples collected from springs recharged in developed and undeveloped areas indicate clear and pronounced differences in water chemistry between the two areas. The main differences are in dissolved ions and nutrients. Possible causes of these differences are most likely directly related to human activities, fertilizer application, roadway runoff, and possibly wastewater line leaks. Indirect causes may be due to reduced recharge because of impervious cover in developed areas. More detailed studies may be able to determine the causes of the differences, sources of contamination, and what development variables have the most impact on groundwater.

Similar effects on groundwater have not been conclusively recognized in Barton Springs, the main discharge point for the Barton Springs segment of the Edwards Aquifer. This is probably due to the tremendous amount of dilution that occurs as water recharged in the developed portion of the aquifer mixes with huge amounts of clean water as regional flow patterns bring water from less-developed areas southwest of Austin toward Barton Springs. Currently, it is unclear how effective water quality ordinances primarily intended to protect surface water resources, and only recently targeting groundwater quality in the Barton Springs segment will be in preventing or reducing groundwater contamination that results from urban development over a karst aquifer like the Edwards.

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# BEDROCK, SOILS, AND MICROTOPOGRAPHY OF A TEST AREA WITHIN THE BARTON CREEK WATERSHED, WESTERN TRAVIS COUNTY, TEXAS[1]

C.M. Woodruff, Jr., L.P. Wilding, and William M. Marsh

Two small tributary watersheds within the Barton Creek drainage basin are part of a test area for examination of soils, landforms, and geomorphic processes west of Austin. The two basins make up typical Hill Country terrain, which is the dissected margins of the Edwards Plateau west of the Balcones Fault Line and Escarpment. The two basins comprise a total of approximately 205 acres (0.32 $mi^2$); the Barton Creek watershed, in contrast, comprises 123.5 $mi^2$, of which 116.1 $mi^2$ (94 percent) lies west of the main Balcones Fault Line. Thus, most of the Barton Creek watershed is contributing catchment for the Barton Springs Segment of the Edwards aquifer, and the two test-area sub-basins occupy the contributing zone, upstream from the aquifer recharge zone. The confluence of the joined sub-basin tributaries with Barton Creek is approximately 5.7 miles upstream from the Mount Bonnell Fault, which marks the western border of the recharge zone. The Mount Bonnell Fault also marks the general trace of the Balcones Escarpment, which is the topographic expression of the main line of the Balcones Fault Zone.

In this part of Travis County, the dominant landscape is dissected Hill Country terrain, which is underlain by Lower Cretaceous limestone units, chiefly the Glen Rose Formation. Hard and soft alternating beds that make up the Glen Rose Formation have resulted in the "stair-step hills" typical of the Central Texas Hill Country. These alternating hard and soft limestone strata impose controls on most other aspects of the land: terrain, soils, vegetation, and surface water and groundwater regimes. Steep slopes are common. Soils traditionally have been regarded as thin and stony, and dominant woody vegetation includes live oak and juniper, with open grasslands maintained chiefly by human intervention. Streams are commonly incised into narrow valleys and canyons with high-gradient ephemeral tributaries feeding main watercourses that are cut deeply enough to receive locally sustaining groundwater discharge. Groundwater occurs erratically from multiple horizons at relatively shallow depths (Brune and Duffin, 1983).

On typical terrain of the Glen Rose Formation, limestone and dolomite beds stand out as ledges capping the "risers" of the stair steps; they also form the resistant substrate underlying individual "treads." In contrast, the marls are eroded back to form the bases of risers. Depending on local topography and thickness of marly strata, undercutting occurs, and eventually the overlying resistant limestone cap collapses, providing an armor of rocky debris across the weathered or exposed marl below.

Variable water-holding and transmitting properties typify the interbedded strata of the Glen Rose Formation: Across most uplands, shallow groundwater is transmitted rapidly through fractures in hard limestone and through fractures and intergranular porosity in dolomite strata. Marly strata, in contrast, typically exhibit lower permeabilities but higher overall porosity. Hence, marly zones retain considerable volumes of water and allow lateral seepage to occur. In this way, more extensive weathering occurs within these fissile, nodular horizons. The combination of ephemeral, perched water tables with steep, locally undercut

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[1] This article is modified from a stop description for the American Institute of Hydrology 1994 Annual Conference.

slopes, promotes the formation of a "two-phase" soil system: The upper part consists of admixed limestone flags and blocks with loamy materials collected on risers owing to mass wasting and deposition from upslope erosion; the lower part consists of residual soils formed by slow seepage within the marly substrate.

Current conventional wisdom recognizes only truncated, stony soils across most of the Hill Country. The dominant soils mapped by the Soil Conservation Service (SCS) compose members of two series, Brackett and Tarrant (Werchan and others, 1974). These soils are described by the SCS as being only about 2 ft thick and are commonly on the order of inches thick. They are noted for their stony content, both at the surface and within the solum, and they are characterized by low water-holding capacity and other hydrologic properties within minimal ranges. Only along stream valleys are there dark-colored, thick, loamy soils (Volente Series as mapped by the SCS). These valley-fill materials meet the commonly-held expectations of soils; hence, popular preconceptions hold these to be the only thick, viable soils throughout the Hill Country.

In fact, as discussed by Wilding (1992), soils have been documented locally on the Glen Rose Limestone terrain as being considerably thicker and more diverse than previously reported. This research has disclosed that high-quality (albeit stony) soils occupy areas of steepest microtopography (riser faces) on the "stair-step" Glen Rose Limestone terrain (fig. 1). On these soils, much incident water infiltrates and is retained and made available for plant uptake. Part of this retained water moves slowly through the soil and shallow substrate and reemerges as surface flow downslope; yet in many places, this runoff is recaptured by another thick-soil riser farther downslope. Because of these processes, this retained water does not contribute appreciably to storm hydrographs. And water thus retained commonly is cycled through biochemical and physiochemical transformers within the soil zone thereby mediating water quality. In contrast, moderately or gently sloping "treads" commonly exhibit soils that are thin or nonexistent, or that have been eroded so that they effectively function as quasi-impervious surfaces. These zones of thin, commonly degraded, soils provide marginal buffers for retention and mediation of incident waters, although some buffering still occurs owing to local surface depression storage and some infiltration into the depauperate soils.

It has long been recognized that, owing to scale of original mapping and the intent of county-wide maps, the use of a standard soil survey and accompanying base map are inappropriate for detailed examination of site-specific soil systems (see Wilding, 1992-b). Soils on the complex Glen Rose Limestone terrain compose a mosaic of materials having highly variable properties. Some soils are degraded, and nearly impervious, as seen on the treads of the stair-step microtopography. Elsewhere, locally disjunct soils have thickness and water-holding qualities that make them excellent environmental buffers.

Our findings demonstrate that, in order to properly assess processes active on complex terrain such as that of the Glen Rose Limestone, one must work with landform elements at a detailed scale of view--one that allows consideration of the microtopography of stepped hillslopes. Accordingly, individual risers and treads are the appropriate objects of study for making sense of soil assemblages, vadose-zone hydrology, and geomorphic processes, although this large-scale focus is not widely recognized by interested parties concerned with environmental problems west of the Balcones Escarpment. Given this perspective, materials and processes (especially locally thick soils and microtopographic changes across riser/tread landforms) may be employed by engineers and planners to provide natural mediation of environmental impacts.

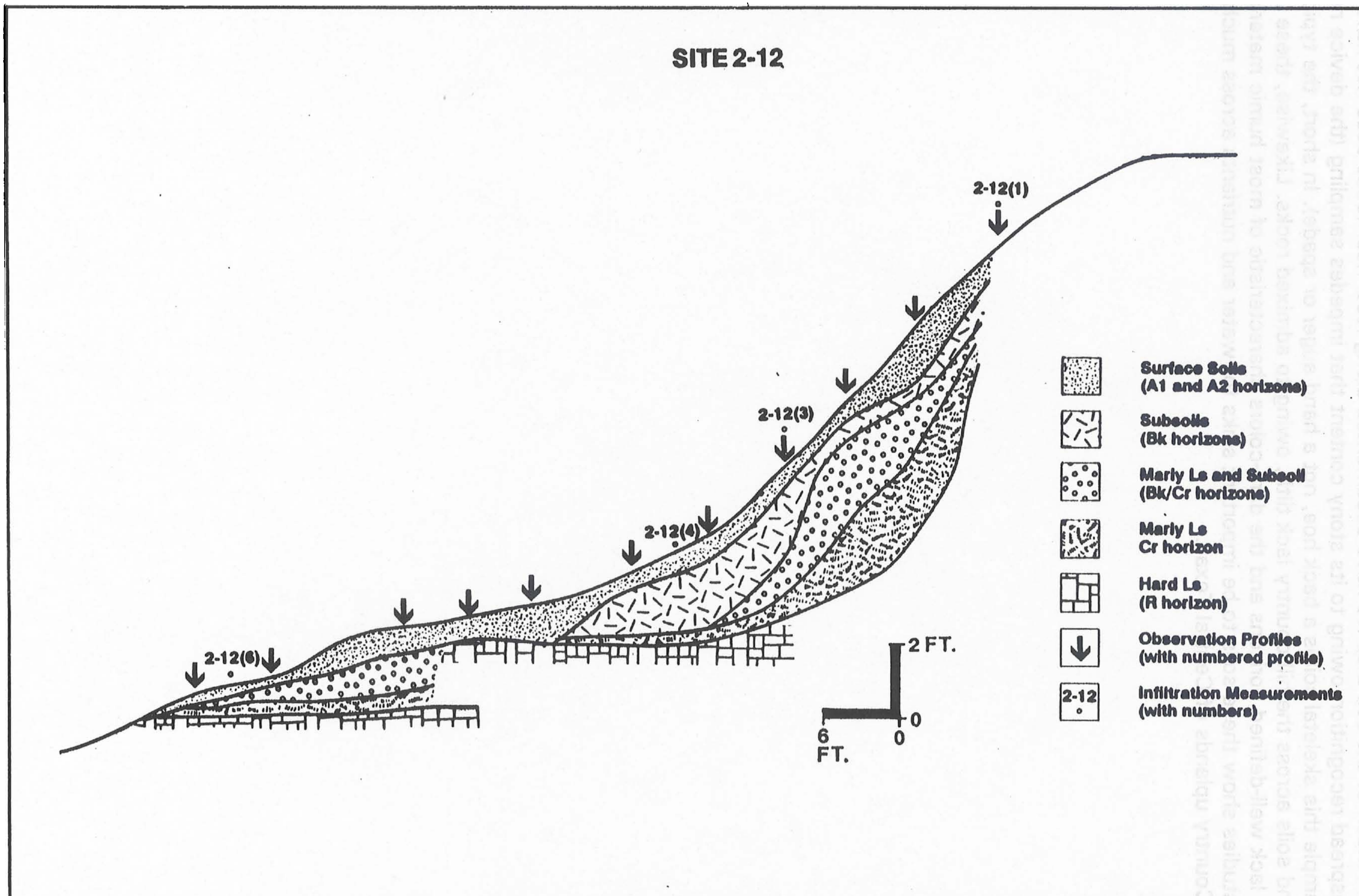


Figure 1. Detailed section of site 2-12 soil trench (from Wilding, 1992).

Much of the soil that we have documented along local riser faces does not have widespread recognition owing to its stony content that impedes sampling (the device needed to sample this skeletal soil is a back hoe, not a hand auger or spade). In short, the typical upland soils across the hill country lack tilth, owing to admixed rocks. Likewise, these upland soils lack well-defined horizons and the dark-colors characteristic of most humic materials. Yet our studies show these soils to be important sinks for water and nutrients across much of the Hill Country uplands of Central Texas.

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# EVOLUTION OF CITY OF AUSTIN WATER QUALITY ORDINANCES AFFECTING BARTON SPRINGS

David A. Johns

This short description on the evolution of City of Austin water quality ordinances protecting areas which recharge the Barton Springs segment of the Edwards Aquifer is not intended to be an all-encompassing, this-is-how-you-do-it, detailed treatise on these ordinances. In fact, these descriptions are intended as an introduction to touch only the surface of what are very detailed and complicated guidelines on development rules over the Edwards Aquifer. This overview provides a look at the provisions and some specific details of development rules contained in each ordinance. This information is compiled from City of Austin material and a brochure from the Hill Country Foundation.

The City of Austin has, from 1980 to 1992, created 6 different watershed ordinances that attempt to protect water quality in the Barton Springs Zone, Recharge and Contributing Zones. These ordinances have generally evolved to become more strict in where and how much development can occur in these areas as a result of obvious loopholes or failures of previous water quality protection measures to protect water quality. The latest of these ordinances, the SOS Ordinance, is currently under numerous legal challenges. Included here are some of the major provisions of these ordinances. You will note a common theme to most ordinances, with earlier efforts targeting specific watersheds, later superseded by more broadly applied ordinances.

## WILLIAMSON CREEK ORDINANCE

This ordinance was adopted December 12, 1980 and was one of the first water quality ordinance enacted by the City of Austin. The ordinance contained impervious cover restrictions for commercial development of 65% of the Gross Site Area (GSA) and 40% of the GSA for residential. Additionally, the ordinance established water quality zones adjacent to drainage ways protected by buffers, restrictions on types of development allowed in the water quality zones, required erosion control measures, required structural controls (i.e. sedimentation ponds), restricted development on steep slopes, required a pre-development environmental assessment, prohibited pre-development clearing of vegetation, and required restoration of disturbed areas.

## BARTON CREEK ORDINANCE

This ordinance was adopted on April 30, 1981 for subdivision-only platting, on November 18, 1982 site development was added, and on December 19, 1985, cluster housing was added. Impervious cover restrictions limited commercial sites to 35% of GSA or 45% if applicant obtained bonus impervious cover by transfer of development rights of the commercial area and residential sites were restricted to 1 unit per 2 acres. As in a number of other ordinances, water quality zones adjacent to drainage ways were established with protective buffers, restricted type of development allowed in the water quality zones, required erosion control measures, required vegetative filter strips for storm water treatment, restricted development on steep slopes, required a pre-development environmental assessment, prohibited pre-development clearing of vegetation, and required restoration of disturbed areas.

## LOWER WATERSHEDS ORDINANCE

The Lower Watersheds Ordinance was adopted May 14, 1981 and revised September 19, 1985. This ordinance covered development activities over the Recharge Zone in the Slaughter, Bear, Little Bear, and Onion Creek watersheds. This ordinance placed impervious cover restrictions of 60% of GSA for commercial development and 30% of GSA for residential. It also established water quality zones adjacent to drainage ways with protective buffers, restrictions on types of development allowed in the water quality zones, required erosion control measures, required both sedimentation and filtration ponds, restricted development on steep slopes, required a pre-development environmental assessment, prohibited pre-development clearing of vegetation, and required restoration of disturbed areas.

## COMPREHENSIVE WATERSHEDS ORDINANCE

The Comprehensive Watersheds Ordinance (CWO) was adopted May 8, 1986. This ordinance included all watersheds in the planning area of the City of Austin with the notable exception of the urban watersheds in the center of the city. The CWO was a major effort to provide uniform development rules for all watersheds. The ordinance restricted impervious cover to 60% of Net Site Area (NSA) for commercial and 40% of NSA for residential. The difference between GSA and NSA is GSA includes the entire tract and NSA includes only the buildable area, so a site with significant unbuildable area, for example steep slopes or flood plains, contained much less impervious cover than previously allowed. Additionally, the ordinance established water zones with development setbacks, had additional development restrictions in the water quality zones, required erosion control measures, required sedimentation and filtration structural controls, restricted excavation and fill depths, prohibited development on steep slopes, required a pre-development environmental assessment, prohibited pre-development clearing of vegetation, required restoration of disturbed areas, contained standards for spoils disposal, protected Critical Environmental Features (including caves, sinkholes, springs, and wetlands), had restrictions over blasting over the Edwards Aquifer, standards for on-site wastewater treatment, and had construction management standards. This ordinance contained a number of exemptions, allowing many tracts to be built under less restrictive ordinances.

## COMPOSITE ORDINANCE

The Composite Ordinance was enacted October 17, 1991 and amended the CWO for areas in the Barton Springs Zone (areas and watersheds which contribute or directly recharge water to the Barton Springs segment of the Edwards Aquifer). Impervious cover restrictions were set at 50% for commercial sites (70% with transfers), and 2 residential units per acre (20%; or 25% with transfers. Additionally, the ordinance established water zones with development setbacks, had additional development restrictions in the water quality zones (generally limited to streets, parks, fences, some water quality control structures, no golf courses, and no wastewater irrigation), required erosion control measures, required sedimentation and filtration structural controls, restricted excavation and fill depths, prohibited development on steep slopes, required a pre-development environmental assessment, prohibited pre-development clearing of vegetation, required restoration of disturbed areas, contained standards for spoils disposal, protected Critical Environmental Features (including caves, sinkholes, springs, and wetlands), had restrictions on blasting over the Edwards Aquifer, standards for on-site wastewater treatment, and had construction management standards. The ordinance added limits on agricultural exemptions for property with no agricultural development approvals, established a maintenance operating permit to assure that water quality controls are maintained, established storm water pollution discharge limits for water quality controls based on four pollutant constituent concentrations (total suspended solids, total phosphorous, total nitrogen, and total organic carbon), required enforcement monitoring of the discharge concentrations for water quality controls, and required fiscal posting for monitoring requirements.

## SOS ORDINANCE

The SOS Ordinance was advanced to a vote by the citizens of Austin through a petition by a strong environmental community that was concerned that the Composite Ordinance was too much of a "compromise" ordinance and would lead to critical water quality degradation. The ordinance was approved in an election on August 10, 1992 by a two-to-one margin. The ordinance has the same development restrictions as the CWO and Composite Ordinances with the very notable additions of impervious cover restrictions with no transfers for all development at 15% of NSA over the Recharge Zone (where the Edwards Aquifer crops out at the surface), 20% of NSA in the Barton Creek watershed contributing zone and 25% of NSA in the aquifer contributing zones of all other recharge creeks (Williamson, Slaughter, Bear Little Bear, and Onion Creeks). Additionally, the ordinance replaced restrictions of the four pollutant discharges with average annual pollutant load requirement of 13 pollutants (total suspended solids, total nitrogen, total phosphorous, and total organic carbon, chemical oxygen demand, biochemical oxygen demand, cadmium, fecal coliform, fecal streptococcus, volatile organics, pesticides, and herbicides), prohibits variances, requires compliance for all approved projects not protected by state law within one year of adoption date, and further restricts development in water quality zones of Barton Creek. This ordinance is currently under several legal challenges.

# STORM WATER EFFECTS ON BARTON SPRINGS

David A. Johns

Barton Springs and Barton Springs pool are a favorite swimming spot for thousands of Austinites and a focal point for innumerable environmental debates in the Austin area. Barton Springs is the main discharge point of the Barton Springs segment of the Edwards Aquifer. Water recharging the aquifer is derived from a beautiful region of the Texas Hill Country that is highly desired for residential and associated commercial development. The effects of this development on the water quality in the draining creeks and Edwards Aquifer are in question. The City of Austin is examining the water chemistry of Barton Springs in several ways to determine how it is being affected by development. One technique is examining the timing and nature of stormwater impacts on Barton Springs and the pool. Knowing the response time of the springs to rainfall provides clues to groundwater travel times in this section of the aquifer, which could be critical if, for example, a major chemical spill occurred over the Recharge or Contributing Zones of the aquifer. The nature of water quality impacts also directly affects habitat for the Barton Spring salamander (up for listing by U.S. Fish and Wildlife as an endangered species), which is currently believed to live only the pool, Eliza Springs adjacent to the north side of the pool, and Sunken Gardens downstream of the pool. Also, monitoring stormwater effects could be a barometer for development impacts in the Recharge and Contributing Zones of the Barton Springs segment of the Edwards Aquifer. It is difficult to monitor directly the effects of development on groundwater quality in karst aquifers, but these impacts may be detectable in the stormwater chemistry of the primary discharge point, Barton Springs.

The Edwards Aquifer is a karst aquifer system with flow conduits that measure from inches to feet in diameter. These conduits originated by dissolution of limestone along zones of primary porosity and permeability, such as burrowed limestone beds and bedding planes, or zones of secondary porosity such as joints and faults. Continued dissolution created an integrated network of conduits, some as large as caves, through which groundwater migrates from recharge to discharge in a pattern convergent toward Barton Springs. The very nature of these conduits imparts to the aquifer its characteristics of rapid recharge and discharge (flashy) and also contributes to its problems of minimal filtration of contaminants. The large flow pathways and relatively rapid water movement prevent extensive cleansing of the water, much less so than in more common sand aquifers. Water "filtration" is probably limited to settling of some suspended solids (sediment and organic debris) as entering recharge waters slow within karst cavities inside the Edwards and Georgetown limestones. Dilution occurs as stormwater mixes with cleaner aquifer water that has run off and recharged in less developed areas, or mixes with aquifer water that has migrated longer distances and so has had more time for contaminants to settle out. Natural degradation of contaminants also likely occurs inside the aquifer.

This article will focus on some short term effects recharging stormwater has on water chemistry of Barton Springs as documented by City of Austin studies and will also discuss the timing of these effects in relation to rain events. Specific effects discussed here are increases in fecal coliform bacteria, turbidity, and changes in specific conductivity.

Previous studies by the U. S. Geological Survey (Slade and others, 1986) have demonstrated the relationship between rainfall and increases in bacteria in Barton Springs. During rains over approximately 1 inch, water running off both developed and undeveloped land over or upstream of the Recharge Zone enters the aquifer and eventually discharges at Barton Springs. Bacteria data have been collected at the pool by Austin-Travis County Health

Department staff and other City staff at least weekly for over 10 years. These data and data from the City of Austin Flood Early Warning System rain gauges in the Barton Springs Zone provide a base to determine how long it takes runoff from rain events to enter the aquifer and discharge from the springs.

Figure 1 plots the number of fecal coliform colonies against time for samples collected following 36 rain events between November 1986 and July 1992, with rainfall totals ranging from 0.75 inches to 3.5 inches. Bacterial data on the springs are not generally available for larger rains because they commonly culminate with flooding the pool, thereby preventing access to the springs for sampling. Sample results indicate a time range in which stormwater effects are first seen in the springs. These effects generally appear no sooner than 10 hours following rain. Based on bacterial densities, stormwater effects can last for over 72 hours, probably depending on many factors, including the amount of rain, intensity of rainfall, duration of rain, location of rain, water level in the aquifer, antecedent moisture conditions, and base flow in recharge creeks.

Rainfall intensity may play an important role in the duration of bacterial effects of stormwater runoff on Barton Springs. Research by the City of Austin (1991) suggests that fecal coliform bacteria concentrations may increase inside the aquifer following particularly heavy rains. These storms flush large amounts of suspended matter into the aquifer which may allow the bacteria to temporarily thrive before dying off. This effect may skew ratios of fecal coliform to fecal streptococcus, used to determine human or animal source of bacteria, as fecal streptococcus appear to die off more rapidly in the aquifer. More rapid dieoff of fecal streptococcus would falsely give bacteria ratios a more human appearance.

Detailed sampling that tracks the effects of a 3 inch rain further delineates the timing of stormwater impacts on Barton Springs, at least under the following conditions: Barton Springs discharge at approximately 102 cfs; Barton Creek flow at Loop 360 at approximately 6.2 cfs (U.S.G.S. Water Resources Data, Texas, Water Year 1993); antecedent moisture conditions are no rain greater than 0.08" for 6 days prior to 11/19/92. Results of sampling indicate stormwater impacts occurred between 12 and 14 hours following rain as indicated by fecal coliform, specific conductivity, and turbidity. Figure 2 illustrates bacterial effects of this storm, showing an increase in bacterial densities from 52 to 550 colonies per 100 ml between 12 and 14 hours. Storm water effects for this rain, as defined by fecal coliform bacteria, lasted for over 72 hours. At this time there are no estimates on the volume of runoff that generates these changes in the springs, other than that heavier rains generally produce longer effects.

Additional changes in water chemistry are also evident, based on the fact that rainwater/stormwater has pronounced chemical differences (turbidity and specific conductivity) with "normal" Barton Spring water. Turbidity is a measure of the cloudiness, or clarity, of water. In springs, it may be caused by suspended matter in the water, generally sediment, plankton, or in some cases organic debris. Turbidity can be a rough measure of the suspended sediment concentration in water and thus, in Barton Springs, an indicator of increased sediment runoff and recharge in its watershed. It is also a safety issue in the pool because as the pool becomes more turbid, life guards can not see far into the water, possibly preventing them from reacting quickly enough to help swimmers in trouble. Under normal conditions, Barton Springs water is crystal clear, with turbidity less than 1 nephelometric turbidity unit (NTU) and total suspended solids of less than 1 mg/l. These conditions can change dramatically following some rains.

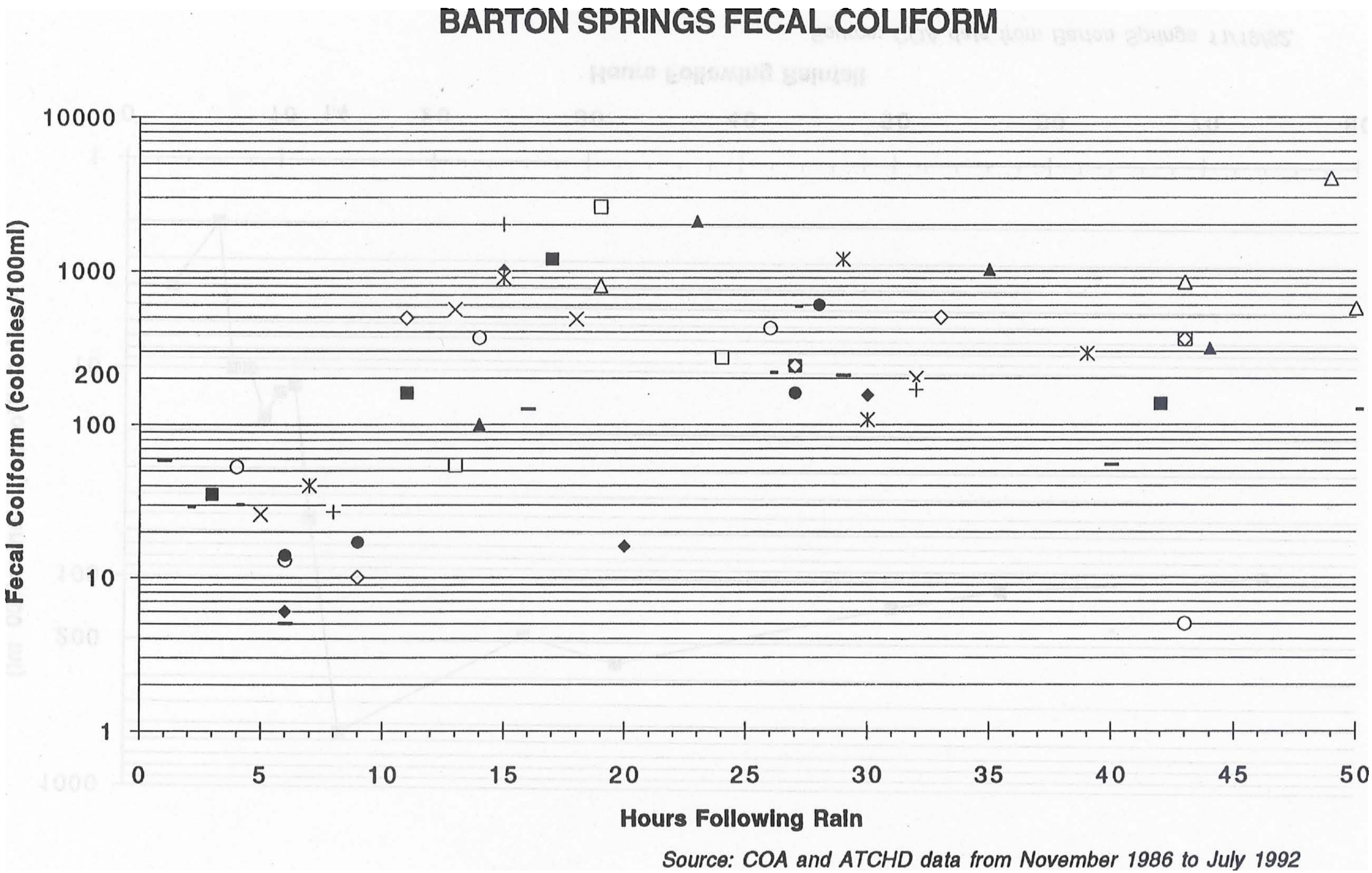


Figure 1. Fecal coliform concentrations in Barton Springs following 36 rain events.

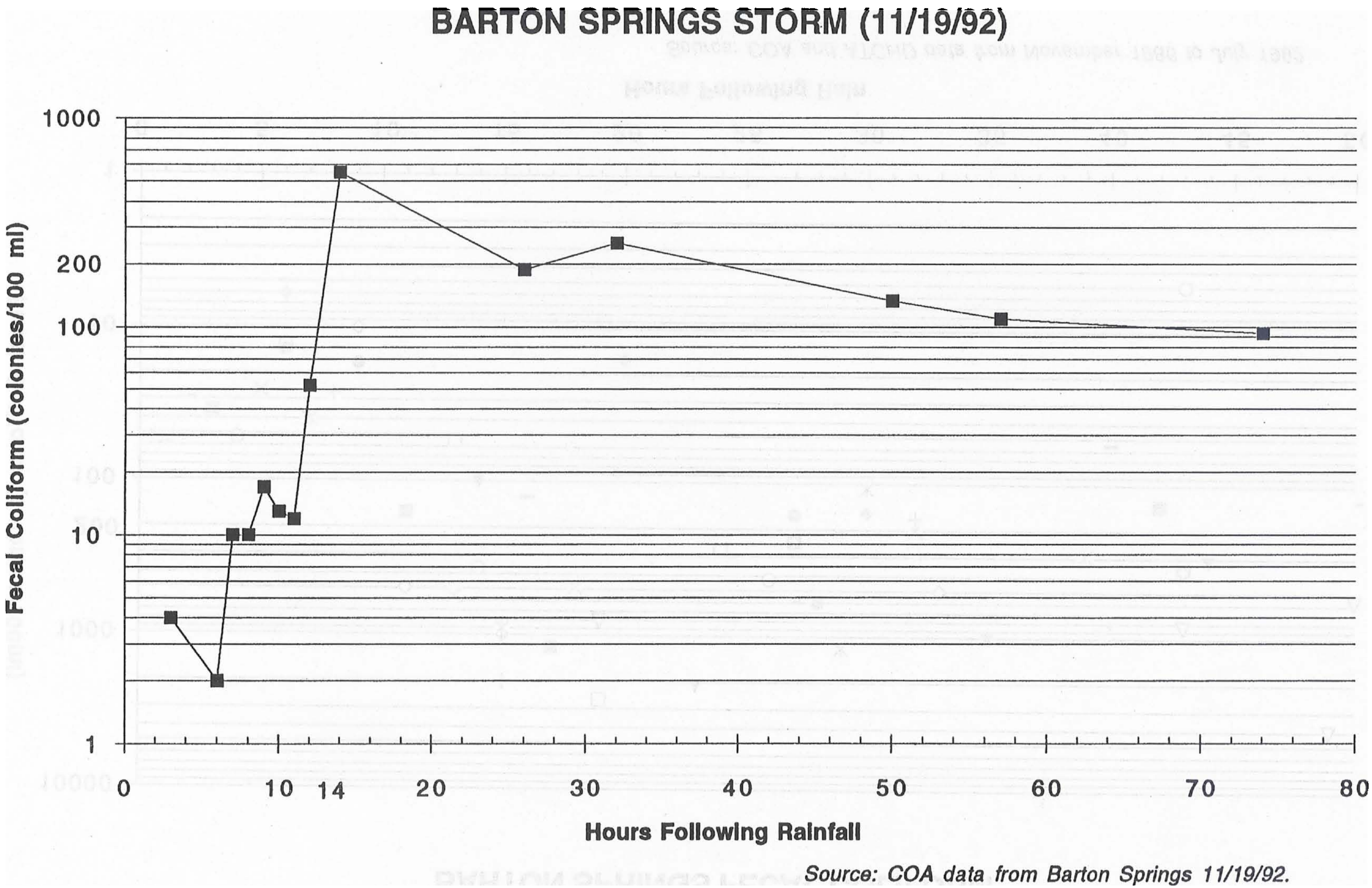


Figure 2. Fecal coliform concentrations in Barton Springs following rain on Nov. 19, 1992.

Figure 4 illustrates the turbidity changes in the springs following the November 1992 storm. For the first 9 hours, turbidity had been relatively steady - below 1 NTU. Beginning at about 10 hours, turbidity doubled and continued to increase to peak at 14 hours into the storm and then steadily decrease over the next 72 hours. The morning following the turbidity peak, Barton Springs pool was cloudy, with visibility a little over 4 feet, based on observations of pool features, and Barton Creek was up and running brown. The slight increases in turbidity, at hours 10 , 11, and 12, prior to the peak in fecal coliform, may be due to a pressure pulse transmitted through the aquifer as recharging water increases the effective head at Barton Springs. This would cause water to flow slightly more rapidly through the aquifer and to pick up and transport sediment previously deposited within cavities in the aquifer.

Specific conductivity is a measure of the ability of water to carry an electrical current and is dependent on the dissolved ionized constituents (total dissolved solids) in the water. Although not a measure of pollution, specific conductivity is useful in tracking stormwater flow from karst springs because recharging water tends to have lower conductivity than "older" aquifer water which has had more time to react chemically with aquifer host rocks. Figure 3 illustrates the change in specific conductivity in Barton Springs during the November 19, 1992 storm. Specific conductivity had been holding constant between 565 and 570 microsiemens until it dropped quickly to about 540 and remained at this new level for over 72 hours. Similar results have been documented by the U.S.G.S. (Slade and others, 1986).

One of the problems in interpreting storm data from Barton Springs is not knowing the precise point or main point of recharge in Barton Creek. Barton Creek is believed to have the greatest impact on the water quality of Barton Springs based on its proximity to the springs ( Slade and others, 1986). Previous studies have documented the recharge rate and percentage of recharge to total spring flow (Slade and others, 1986; BS/EACD unpublished data, 1991) with Barton Creek providing approximately 28% of total recharge with a maximum recharge rate between 30 and 70 cfs (Slade and others, 1986), depending on water level in the aquifer. Geologic maps indicate numerous faults crossing Barton Creek in the vicinity of Loop 360 from MoPac to Gus Fruh Park, including the Barton Springs fault from which the springs discharge in the pool. This fault may provide nearly direct access from Barton Creek to the pool. In fact, recent studies by the Barton Springs/Edwards Aquifer Conservation District (Hauwert and Vickers, 1994) have documented a trough in the Edwards potentiometric surface aligned along this fault, indicating flow paths converging to the fault. Currently, it is not precisely known if the stormwater runoff affecting Barton Springs is recharging in the channel of Barton Creek or in one of the tributary channels. Williamson Creek is also relatively close to Barton Springs in the area of Ben White Blvd. and South Lamar and could also be contributing to the rapid degradation of spring water following storms.

For the purpose of discussion, assume that the bulk of water recharging the aquifer and discharging from the springs quickly is being recharged in the Loop 360 area. This means that water affecting the springs is running off, recharging, migrating about 12, 000 feet, and discharging from the springs within 14 hours of rainfall. Assuming this occurs in 14 hours yields a hydraulic conductivity of about 855 feet per hour (0.16 mi/hr; 14.3 ft/min; 0.23 ft/sec; or 7 cm/sec) for this section of the aquifer. These are obviously very rapid rates of movement for groundwater but are comparable to flow rates documented in other karst systems; 66-656 ft/hr in the Swabian Alb karst aquifer in southern Germany (Teutsch and Sauter, 1992), 865 ft/hr in the Carboniferous Limestone of England (Atkinson, 1977). Flow rates for well sorted gravel aquifers range from 1.18-118 ft/hr (0.01 to 1 cm/sec) and silty sand or fine sand aquifers range from 0.00118-0.118 ft/hr (0.00001 to 0.001 cm/sec) (Fetter, 1988).

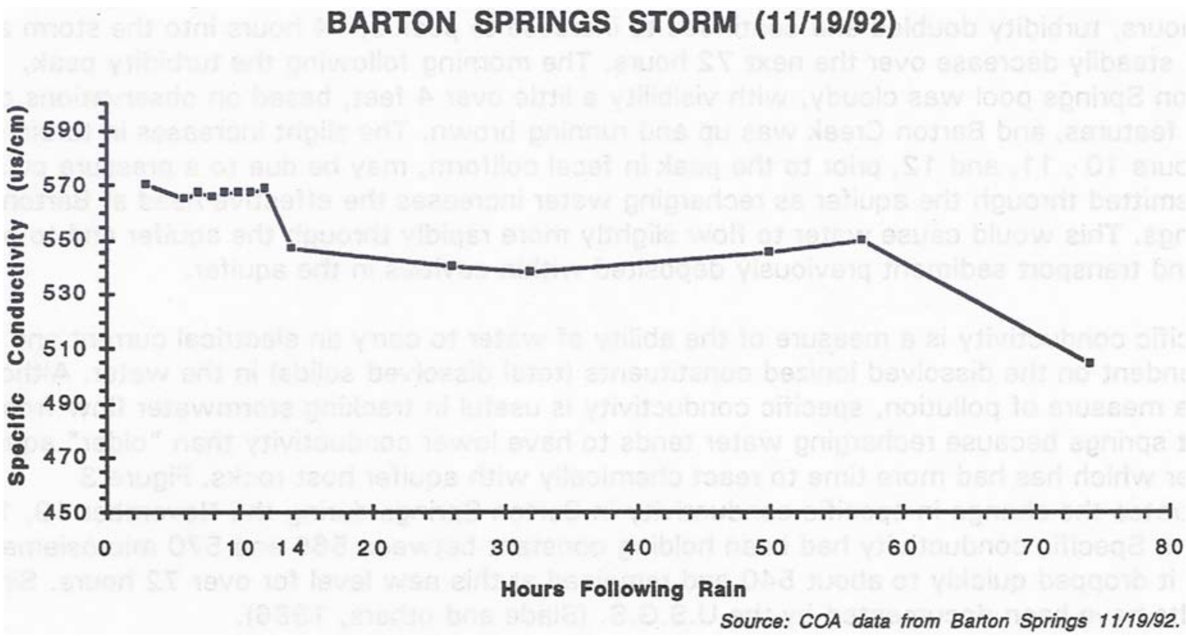


Figure 3. Specific conductivity in Barton Springs following rain on Nov. 19, 1992

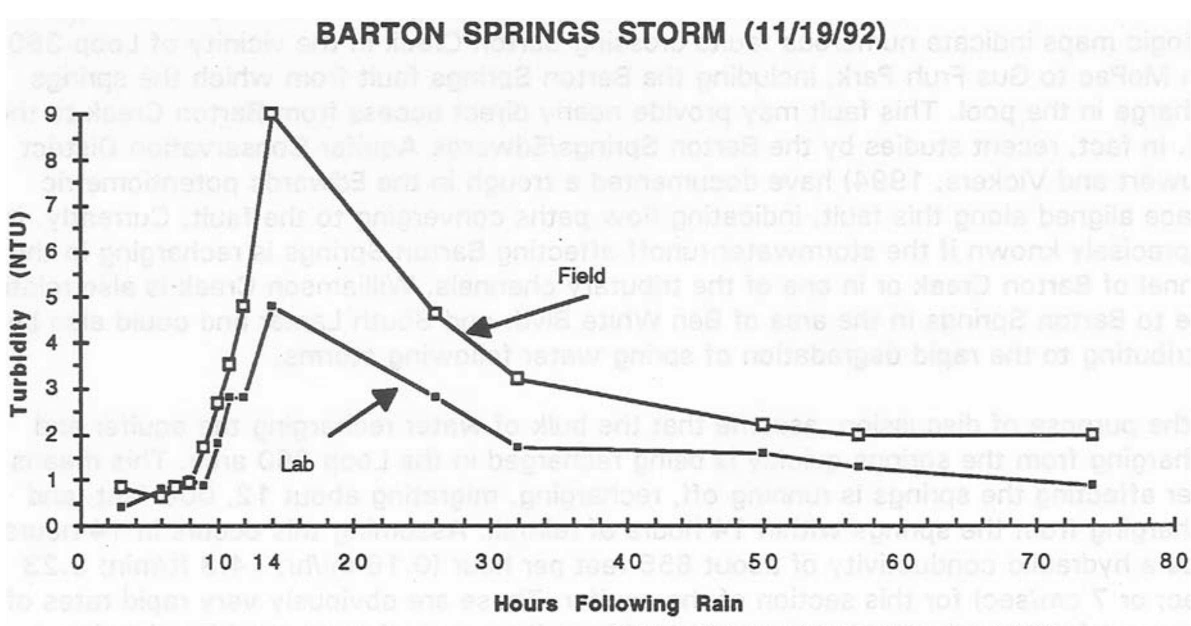


Figure 4. Turbidity in Barton Spring following rain on Nov. 19, 1992

Additional studies are necessary to refine flow rates in this section of the Edwards aquifer. Studies by the City of Austin are currently underway to gather additional data from Barton Springs to refine spring response to rainfall. Analysis of estimated flow rates based on the Loop 360 recharge area under different aquifer levels, flow conditions in Barton Creek, rainfall intensities, and rain locations would illuminate the mechanics and dynamics of how stormwater affects Barton Springs.

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**FIELD TRIP ROAD LOG**
**EDWARDS AQUIFER--WATER QUALITY AND LAND DEVELOPMENT**
**in the**
**AUSTIN AREA, TEXAS**

David A. Johns and C.M. Woodruff, Jr.

0.0 Depart from Barton Springs Pool parking lot.

0.1 Turn left by Knights of Columbus headquarters.

0.5 Turn left and proceed immediately to Loop 1 (MoPac Expressway) access road; cross under freeway; turn left onto southbound access lane.

1.0 Turn left beneath freeway onto north-bound access road.

1.2 Merge onto Loop 1-North.

1.8 Cross Colorado River/Town Lake; proceed north on Loop 1.

4.3 Exit to 35th Street.

4.6 Turn left at traffic light; proceed west on 35th Street; cross freeway.

5.4 At stop sign (intersection with Balcones Trail), proceed straight.

5.6 On right, Davis Water Treatment Plant; on left is Mayfield Park.

5.7 Turn right onto Mt. Bonnell Road.

5.9 Cross Hucks Slough; we are at the foot of the Balcones Escarpment. We cross the Mt. Bonnell Fault as we begin the steep ascent of the Escarpment.

6.4 STOP 1--MOUNT BONNELL

At this stop, we ascend to the top of Mt. Bonnell and discuss the overall context of the field trip in terms of the Balcones Fault Zone and incision of streams and rivers. Two companion articles by Woodruff: "Balcones Fault Zone and Colorado River..." and "Atop Mount Bonnell" explore the themes presented here.

After departing from Stop 1, proceed straight on Mt. Bonnell Road, and bear left at intersection where Mt. Bonnell Road bends to the right.

6.5 Note stunning view of Lake Austin, as we descend through the uppermost dolomitic strata of the Glen Rose Limestone.

7.2 Dry Creek Boatdock on left, a noted Austin beer joint with a marvelous view, a great juke box, dubious foundation stability, and notoriously dirty restrooms.

7.6 Cross unnamed slough.

8.0 Turn right on Ranch-to-Market (RM) 2222.

8.6 At traffic light, turn left onto Mesa Drive; here we proceed uphill across the upper Glen Rose Limestone, the Walnut Formation, and cross onto the basal Edwards Limestone, which caps the summit of this southern finger of the Jollyville Plateau.

9.2 Ascend across the basal contact of the Edwards Limestone.

9.3 At stop sign (Cat Mountain Drive), proceed straight.

10.0 At stop sign (Far West Drive), turn right.

10.4 Descend from crest of reclaimed limestone quarry.

10.6 Turn left into strip shopping center along north wall of reclaimed quarry.

10.7 STOP 2--RECLAIMED TEXAS CRUSHED STONE QUARRY

This stop provides an excellent opportunity to view porosity development in part of the Edwards Aquifer. Here we note development of meso-pores as well as enhancement of porosity (mega pores) along fractures. The location provides a case study in the arcane lithostratigraphy near the base of the Edwards Limestone. According to Young (1986) and depending on whose stratigraphic conventions are followed, this outcrop is either part of the upper Cedar Park Limestone, the Buttercup Creek Dolomite (both members of the Walnut Formation), or part of the basal Edwards Limestone. Young's interpretation is presented (Fig. 1), but irrespective of stratigraphic interpretation, the site gives a good inside view of what we may expect the Edwards Aquifer to look like in certain parts of the section. This stop also presents an interesting case of multiple, sequential land use; among other facilities, the quarry now is the site of Murchison Junior High School.

10.8 Retrace route out of parking lot; turn right on Far West and return to Mesa.

11.4 At stop sign, turn right onto Mesa and proceed north.

11.7 At 4-way stop (Graystone), proceed straight.

12.0 Turn left onto Burney.

12.4 At stop sign (intersection with West Rim Drive), turn right and park.

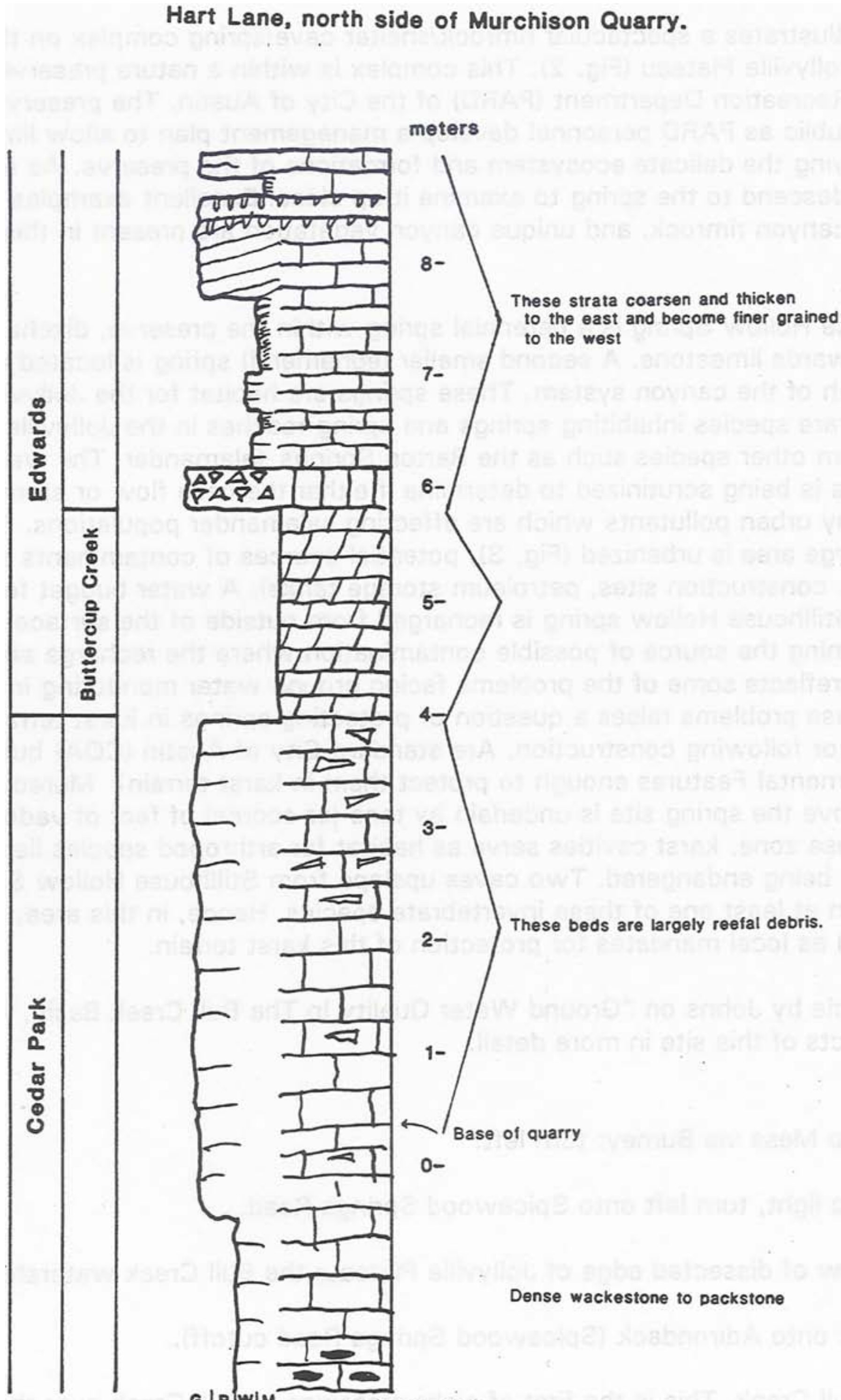



Figure 1. Measured section along northern side of reclaimed Texas Crushed Stone Quarry (from Young, 1986).

STOP 3--STILLHOUSE HOLLOW SPRING CAVE COMPLEX

Stop 3 illustrates a spectacular rimrock/shelter cave/spring complex on the margins of the dissected Jollyville Plateau (Fig. 2). This complex is within a nature preserve operated by the Parks and Recreation Department (PARD) of the City of Austin. The preserve is currently closed to the public as PARD personnel develop a management plan to allow limited visitation without destroying the delicate ecosystem and formations of the preserve. As a result, we will not be able to descend to the spring to examine it up close. Excellent examples of springs, shelter caves, canyon rimrock, and unique canyon vegetation are present in this outdoor laboratory.

Stillhouse Hollow Spring is a perennial spring within the preserve, discharging from the base of the Edwards limestone. A second smaller (ephemeral) spring is located at the head of the north branch of the canyon system. These springs are habitat for the Jollyville salamander, a rare species inhabiting springs and spring reaches in the Jollyville Plateau area and distinct from other species such as the Barton Springs salamander. The water chemistry of these springs is being scrutinized to determine if either the base flow or storm flow is contaminated by urban pollutants which are affecting salamander populations. Since the entire potential recharge area is urbanized (Fig. 3), potential sources of contaminants are numerous (streets, lawns, construction sites, petroleum storage tanks). A water budget for this area suggests that Stillhouse Hollow spring is recharged from outside of the surface drainage divide. Determining the source of possible contamination where the recharge area is not clearly defined reflects some of the problems facing ground water monitoring in karst terrain. Considering these problems raises a question of protecting springs in karst terrain from damage during or following construction. Are standard City of Austin (COA) buffers around Critical Environmental Features enough to protect them in karst terrain? Moreover, most of the uplands above the spring site is underlain by tens (or scores) of feet of vadose zone. And within the vadose zone, karst cavities serve as habitat for arthropod species listed by the U.S. Government as being endangered. Two caves upslope from Stillhouse Hollow Springs are know to contain at least one of these invertebrate species. Hence, in this area, there are Federal, as well as local mandates for protection of this karst terrain.

The article by Johns on "Ground Water Quality In The Bull Creek Basin, Austin, Texas" discusses aspects of this site in more detail.

12.9 Return to Mesa via Burney; turn left.

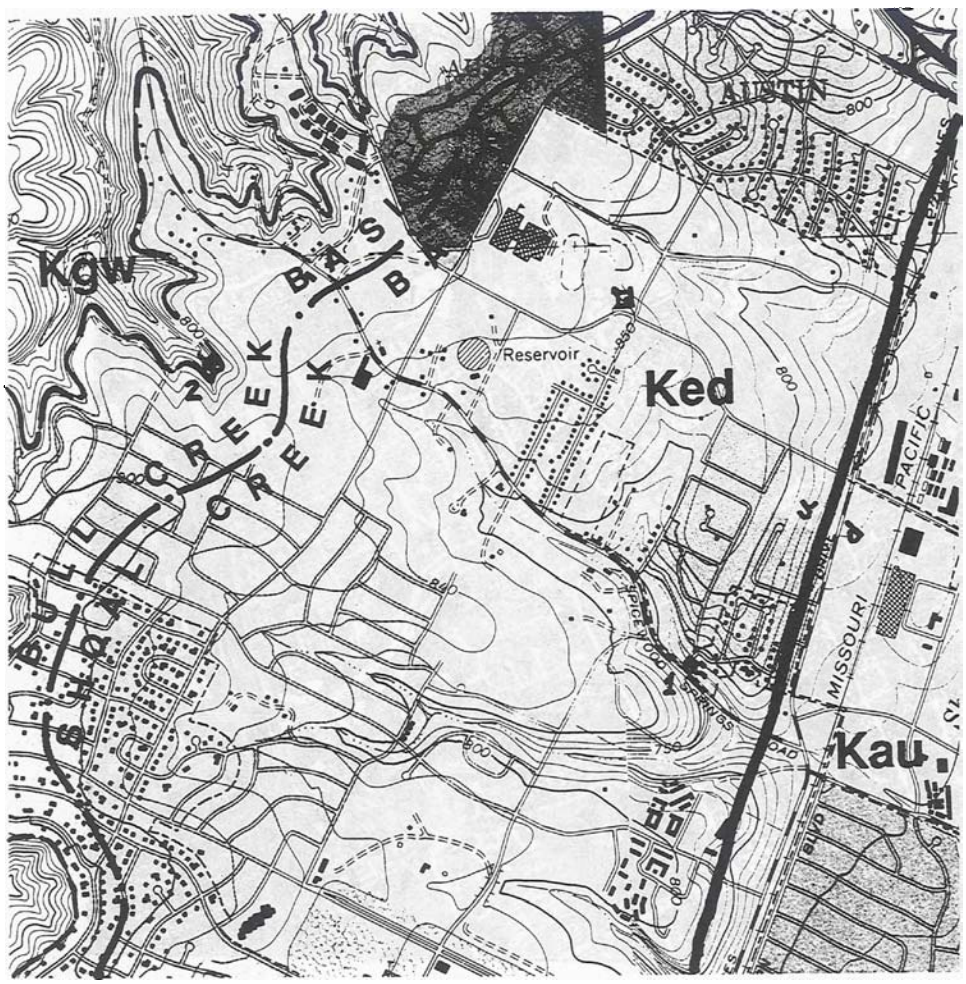
13.2 At traffic light, turn left onto Spicewood Springs Road.

14.0 Note view of dissected edge of Jollyville Plateau; the Bull Creek watershed lies below.

14.2 Turn left onto Adirondack (Spicewood Springs Road cutoff).

14.5 Cross Bull Creek. This is the first of eight crossings of Bull Creek over the next five miles, as we traverse the valley of this deeply incised stream.

14.6 Turn right on Spicewood Springs Road; proceed along valley of Bull Creek. Note dense cedar brakes.




Explanation:

Kau -- Austin Chalk
Ked -- Edwards Limestone
Kgw -- Glen Rose and Walnut Formations

Figure 2. Southeastern finger of Jollyville Plateau including sites of Spicewood Springs (1) and Stillhouse Hollow Springs (2); basal outcrop of Edwards and trace of Mount Bonnell Fault from Garner and Young (1976).

Figure 3. Aerial photograph of Northwest Hills, Austin, depicting roughly the same view as Figure 2.

15.1 Cross Bull Creek.

15.4 Cross Bull Creek.

15.8 Cross Bull Creek.

16.2 Cross Bull Creek.

16.7 Cross Bull Creek, and pass St. Edwards Park (City of Austin).

17.0 Note property of "cedar choppers," a well-recognized cultural type of the Central Texas Hill Country. They typically are of Anglo-Saxon stock and are likely descendants of Appalachian hill folk (with a tradition of strong clan ties, occasional violence, and moonshining). Although considered by some to be "poor white trash," they are seen by others as rugged individualists left in the backwash of the frontier movement when there was no more frontier to conquer (Peter R. Rose, personal communication, 1994). Cedar chopping is a long-time traditional vocation in these parts; for fine writing on the culture and the work of these people, see John Graves's Hard Scrabble (Knopf, 1972).

17.7 Cross Bull Creek.

17.9 Cross Bull Creek.

18.1 Turn left onto Old Lampasas Trail; note outcropping Glen Rose Limestone on right.

18.5 End of pavement; proceed straight.

19.1 Turn left into entrance of ranch; proceed through gate.

19.6 STOP 4--SPRINGS AT EDGE OF JOLLYVILLE PLATEAU AND ALONG CREEK/ UNDEVELOPED BULL CREEK SPRING

At this stop we will discuss differences in the water chemistry of these rural springs versus the urban spring seen at the last stop, be introduced to biological assessment of water quality, and see some of the water quality benefits of habitat protection and land purchases in the Bull Creek watershed.

The tract we are on, the Gleasman, Franklin, or 151 tract, contains 151 acres of land purchased by the City of Austin as a nature preserve for the golden-cheeked warbler. During the spring, warblers nest in this area following their long migration from Central America. Additional City-owned property extends upstream to near the head of the main branch of Bull Creek as well as the area around the tributary confluence in the canyon just north of here.

Two spring systems can be viewed here. There is an Edwards/Walnut spring on the west slope of the draw across the creek from the house. This spring discharges over 10 gpm from a small karst cavity on the slope. This is an unusual location for a spring as most Edwards springs are associated with canyon heads. This cavity appears to be in either the Keys Valley marl/Whitestone Limestone or Cedar Park Limestone, which are commonly included in the Walnut Formation. Note the abundant vegetation below the springs, including spice bush, big blue stem, and maidenhair fern. Other Edwards springs can be found on this tract in small canyon head grottos and typically have discharges below 2-3 gpm. Because the Jollyville Plateau is so dissected, effectively preventing long distance migration of ground water, these Edwards springs are probably recharged only on the undeveloped plateau above the springs.

An excellent example of a Glen Rose/alluvial spring can be seen in the channel and on the east side bank of the main creek. Under dry conditions, flow begins in Bull Creek at this spring. The spring is characterized by an extensive bank of maidenhair fern with water seeping out of the far bank in numerous locations and welling up in the channel along small joints and fractures. A large pit was dug on the far bank by the former land owner when he was exploring options for bottling this water.

The water quality on this tract is excellent due to the lack of extensive development in the watershed upstream or in the spring recharge areas. See the Bull Creek ground water article for specific data on water chemistry of the springs. Data on surface water quality on this tract is available in the City of Austin Bull Creek Watershed Study 1993 report. Also, biologic assessment of aquatic habitat is a technique of growing importance due to its unique ability of evaluate impacts of pollution on aquatic species most exposed to it.

After departing Stop 4, retrace route back to Old Lampasas Trail, and back onto Spicewood Springs Road.

20.6 Pavement commences again.

21.0 Turn right onto Spicewood Springs Road, and return back down Bull Creek valley to Loop 360.

24.5 Turn right onto Loop 360.

25.1 Cross Bull Creek.

25.6 Cross Bull Creek.

26.4 Past exit and overpass for Bull Creek Road (RM 2222), note (to the right) deposit of admixed alluvium and colluvium at edge of incised valley near the confluence of West Fork Bull Creek with the main stream.

27.0 Note seepage from cut face of Glen Rose Limestone.

27.2 At traffic light (West Courtland) proceed straight and cross Lake Austin via steel arch bridge. Note bluffs above lake formed in Glen Rose Limestone.

28.6 Proceed straight at traffic light (Westlake Drive).

29.0 Proceed straight at traffic light (St. Stephens School Road).

29.5 Note joint planes within Glen Rose Limestone; discolored rock along joints indicate localized groundwater movement (and weathering) mainly along these fractures.

29.9 Entrance to Wild Basin Preserve on left.

31.4 Ascend stratigraphic section that includes upper Glen Rose Limestone, Walnut Formation, and (above road level) is capped with Edwards Limestone.

31.8 Exit to Bee Cave Road.

31.9 Turn right; proceed west on Bee Cave Road.

33.0 At traffic light, turn left onto Barton Creek Boulevard.

33.8 Cross Barton Creek; note unusual structural members of what we call the "Stegasaurus Bridge."

35.0 Turn right onto caliche road.

35.2 STOP 5--BARTON CREEK PROPERTIES

At this stop, we will examine soils, bedrock, and micro-landforms that make up this part of the contributing zone upstream from the Barton Creek segment of the Edwards Aquifer. We will also discuss ramifications on water quality and residential development. See accompanying article by Woodruff, Wilding, and Marsh.

Upon departing from Stop 5, turn around and return to Barton Creek Boulevard; turn right and proceed to Lost Creek Boulevard.

36.1 Turn left on Lost Creek Boulevard; we are driving through the Estates of Barton Creek (part of the ill-fated Barnes-Connelly partnership).

36.9 Cross Thomas Springs Branch (tributary to Barton Creek).

37.1 Note outcropping Glen Rose Limestone.

37.7 View of Lost Creek residential development on hillsides ahead.

38.7 Cross Barton Creek; Lost Creek Golf Course is upstream to left.

40.0 At stop sign (Quaker Ridge), proceed straight.

40.7 At Loop 360, turn right; note view of downtown Austin on the left side of road.

41.2 Proceed straight at traffic light at Westlake High Drive.

41.4 Cross Mount Bonnell Fault--we are traveling from Glen Rose Limestone to Edwards Limestone; enter recharge zone of Barton Springs Segment of aquifer. Note water-quality filtration pond on right.

42.7 Turn left at Walsh Tarlton (at traffic light).

42.8 We are crossing the contact between Del Rio Clay and the overlying Buda Limestone; note Del Rio Clay along roadside. Note the "washboard" road that results from the plastic clay substrate and ongoing downhill creep.

42.9 In mall parking lot, note faulted outcrop of Buda Limestone and Del Rio Clay.

43.1 Turn right onto Tamarron; bank on the southwest side of this intersection was breaking up owing to insufficient foundation design on the weak clay substrate--a different kind of "bank failure."

43.4 Note expanse of impervious cover that comprises Barton Creek Mall and its parking lot.

43.5 Enter mall parking lot; cross Tamarron and proceed on foot to water-quality filtration pond below new apartment complex.

STOP 6--BARTON CREEK MALL WATER-QUALITY FILTRATION POND

At this stop we will discuss the operations of a filtration water quality control structure, some specific water quality data from this particular pond, the evolution of water quality ordinances requiring such controls, and construction and related sediment/turbidity problems in the aquifer.

Barton Creek Square Mall was constructed in about 1980 by essentially removing the top of the hill above the pond. These water quality ponds were the first to be built in the city, although this construction predated ordinances affecting Barton Creek; the ponds were a condition of zoning approval by the City Council. The mall covers approximately 100 acres and is located in the Barton Creek watershed and occupies the recharge zone of Barton Springs. Water drains from the mall to areas on Barton Creek which are suspected of being major recharge sites. The mall itself is built over the Del Rio Formation, a dark clay which is a poor foundation substrate (Garner and Young, 1976). Several faults also cross this area (Rodda and others, 1970) which may enhance recharge into the aquifer. Construction of the mall was coincident with reports of severe turbidity problems in Barton Springs pool, the first of what now are common occurrences.

This pond is an on-line structure designed as a filtration basin and water detention pond. Up to 1/2 inch of runoff from about 47 acres of the mall, at 86% impervious cover, and 32 acres of mixed land use, mostly undeveloped woods and residential sites west of here, is detained and treated by the pond. subsequently, runoff from the apartment above the pond was routed in for treatment. The pond has about 3.5 acre-feet of storage for the first 1/2 inch of runoff with a total storage capacity of 16.6 acre-feet for a 100-year storm. The filtration bed has a surface area of 1/2 acre. The bed is composed of three layers: a top of 18 inches of fine sand, a middle of 12 inches of coarse sand, and a bottom 6 inches of gravel. Water percolates through these layers into 6-inch perforated pipes which drain to the discharge point at the north end of the pond. The pond is lined with clay to prevent water infiltration into the underlying Edwards Aquifer. Average outflow time was about 26 hours. (COA/ECSD, 1990a, b)

In a cooperative program by the USGS and COA, 23 storms were monitored between September 1982 and August 1984. Results indicate wide variation in removal efficiencies for different water quality parameters. Generally, efficiencies were in a range from 20 to 60 percent; higher efficiencies for metals and total suspended solids and lower efficiencies for nutrients and bacteria. Total dissolved solids and nitrate-nitrite actually had negative efficiencies due to leaching material from the sand filter media. Removal efficiency differs for each pond. Data suggested that water was still infiltrating at this site despite the clay liner (COA/ECSD, 1990a, b).

Specific details to note at this site include: the check dams constructed to slow the flow of water across the sand surface and prevent channeling; the rock berms on the ends of the check dams with some erosion still apparently occurring; and the black stain on the top layer of sand.

A question this type of development raises is: Is high density (high impervious cover) development compatible with goals of non-degradation of water quality?

Detailed data and information on this site and others can be found in the following publications:

City of Austin, 1990a, Stormwater Pollutant Loading Characteristics for Various Land Uses in the Austin Area: Final Report.

City of Austin, 1990b, Removal Efficiencies of Stormwater Control Structures: Final Report.

Welborn, C. T., and Veehuis, J. E., 1987, Effects of Runoff Controls on the Quantity and Quality of Urban Runoff at Two Locations in Austin, Texas: Prepared in Cooperation with the City of Austin, USGS Report No. 87-4004.

After departing from Stop 6, return to Tamarron and proceed left to Loop 1 southbound access road.

43.6 Note unstable slopes below mall parking lot (Del Rio Clay).

44.1 Merge onto Loop 1 access road.

44.4 Left turn to northbound access road.

45.0 Merge with northbound access road; enter freeway. Note cut slopes in Del Rio Clay; slope failure occurs periodically.

45.3 On left, note view of filtration ponds for mall and apartment complex.

46.1 Exit to 2244 (Bee Cave Road/Barton Springs Road).

46.6 At traffic light/intersection with Bee Cave Road and Wallingwood, proceed straight.

47.0 Pass Zilker Park on right (where we left the park at the beginning of field trip).

47.5 Turn right into Zilker Park; proceed to pool parking lot.

47.7 STOP 7--BARTON SPRINGS: GENERAL FACTS AND FIGURES

Barton Springs is our last stop for this field trip and a chance to wrap-up the story we have tried to weave. Much has been said and written about Barton Springs, some right, some wrong. Barton Springs has been a focal point for water quality and environmental issues in the Austin area for years and is currently the center of a frenzy of litigation. Due to these circumstances, we will present just a few facts and figures here to get the lawyers off our scent.

The Barton Springs segment of the Edwards Aquifer differs from the Jollyville Plateau Edwards in many respects. In the Jollyville Plateau area, the Edwards is only about 100 feet thick (locally up to 200 feet), is recharged mostly by direct infiltration of rainfall, has a recharge area of approximately 50 square miles, and has a divergent subsurface drainage network when viewed regionally (i.e. ground water flows to many different, local discharge points). In contrast, the Barton Springs segment the Edwards is over 300 feet thick, is recharged via creeks which receives runoff from 264 square miles of contributing watersheds and 90 square miles over the recharge zone, and has a convergent subsurface drainage network (i.e. ground water migrates and coalesces with ground water recharged in other areas to discharge at a common point -- Barton Springs).

Barton Springs is the main discharge point for the segment of the Edwards Aquifer extending from Kyle just north of the Blanco River to the Colorado River. The springs discharge into Barton Springs pool, a favorite swimming spot for thousands of Austinites and a focal point for many environmental debates in the Austin area. Number publications have reviewed the geology and nature of the Edwards limestone and the aquifer in general (see Senger and Kreitler, 1984; Andrews and others, 1984; Woodruff and Slade, 1984; Slade and others, 1986; and Rose, 1972 for example). Suffice to say that the Edwards Aquifer is a karst aquifer system with flow conduits that measure from inches to feet in diameter. These conduits originated by dissolution of limestone along permeable zones which include faults, fractures, joints, and bedding planes. Discharge from Barton Springs averages about 50 cubic feet per second (or 32 million gallons per day) with a low of 10 cfs in 1956 and a high of 166 cfs in 1941 and 1992. Barton Springs is the fourth largest spring in the state, being exceeded only by Comal, San Marcos, and San Felipe Springs (Brune, 1981), all of which discharge from the Edwards Aquifer.

Recharge to the Barton Springs segment is mainly in the channels of the major creeks which flow across the outcrop of the Edwards and Georgetown limestones. It is estimated that 85% of the water discharging from Barton Springs is recharged in Barton (28%), Williamson (6%), Slaughter (12%), Bear (10%), Little Bear (10%), and Onion (34%) Creeks (Slade and others, 1986). The remaining 15% is believed to recharge from direct infiltration of rainfall in uplands areas, in tributaries of larger creeks, or by seepage from other aquifers. The outcrop of the Edwards covers only about 90 square miles (Recharge Zone) although the watersheds of contributing creeks recharging the aquifer constitutes an additional 264 square miles (Contributing Zone). The combination of these two zones is what is referred to as the Barton Springs Zone. Recharge can be through large karst openings, such as Dead Man's Cave on Onion Creek or through numerous smaller opening obscured by alluvium in the channels.

Water chemistry, or water quality, of Barton Springs varies with discharge and changes relatively quickly following rains in the range of 1 inch or greater (see article in this guidebook). Overall, the quality of the water is very good. The problem is will it stay that way as urban development extends further into the Recharge and Contributing Zones. Specific water chemistry can be found in USGS publications Andrews and others (1984), Slade and others (1986), Senger and Krietler (1984), and in annual USGS Water Resource Data publications. Additional unpublished data is available from the Austin-Travis County Health Department, and City of Austin/ECSD.

Several City of Austin Ordinances provide at least some protection of water quality in the watersheds recharging Barton Springs (see article on COA ordinances in this guidebook). Additional layers of protection are provided by: the Barton Springs/Edwards Aquifer Conservation District (BSEACD) which currently has jurisdiction over the Recharge Zone area and an extended service area; the Texas Natural Resource Conservation Commission which enforces the Edwards Aquifer Rules over the Recharge Zone; and potentially, the U.S.

Environmental Protection Agency could be involved if the Barton Springs salamander is listed as an endangered species. A complicated picture!

Features of Barton Springs to note from the porch of the bathhouse:

- o Barton Springs pool, over 1000 feet long and up to 15 feet deep;
- o Barton Springs discharge from the fault, associated fractures, and along the edge of the ledge visible in the pool upstream of the fault;
- o The main fault from which the springs discharge, visible by the last life guard stand to the right on the south (far) side, putting the Georgetown limestone on the east (left) against the Edwards limestone on the west (right), slickenslides are visible on some exposures;
- o Several small faults and fractures are visible upstream (right) of the main fault, note the sag;
- o Terrace deposits of ancestral Barton Creek are visible on the south (far) bank upstream of the fault. These are distinguishable from Colorado River terrace deposits by their lack of igneous rock fragments, lack of micaceous minerals, and exclusive limestone/chert composition.
- o Upper Barton Spring is about 200 feet upstream of the diversion dam and only flows when aquifer levels are relatively high;
- o Eliza or Concession Springs is aligned along the Barton Springs fault and discharges in the former spa east of the concession stand behind us and downstream;
- o Old Mill Spring discharges into a deteriorating Civilian Conservation Corps spa several 100 feet downstream from the end of the pool on the south side of the creek;
- o When Barton Creek is flowing at relatively low volumes across the recharge zone, the creek water enters a bypass at the diversion dam forming the upper end of the pool and passes under the north sidewalk to discharge back into Barton Creek below the lower dam, water spills into the pool during flooding following heavy rains;
- o Barton Springs, Eliza Springs, and Sunken Gardens are the only known home of the Barton Springs salamander.

In the mind of many, the burning question is: Will we still be able to swim in the natural waters of Barton Springs 20 years from now? 50 years?

End of Trip.

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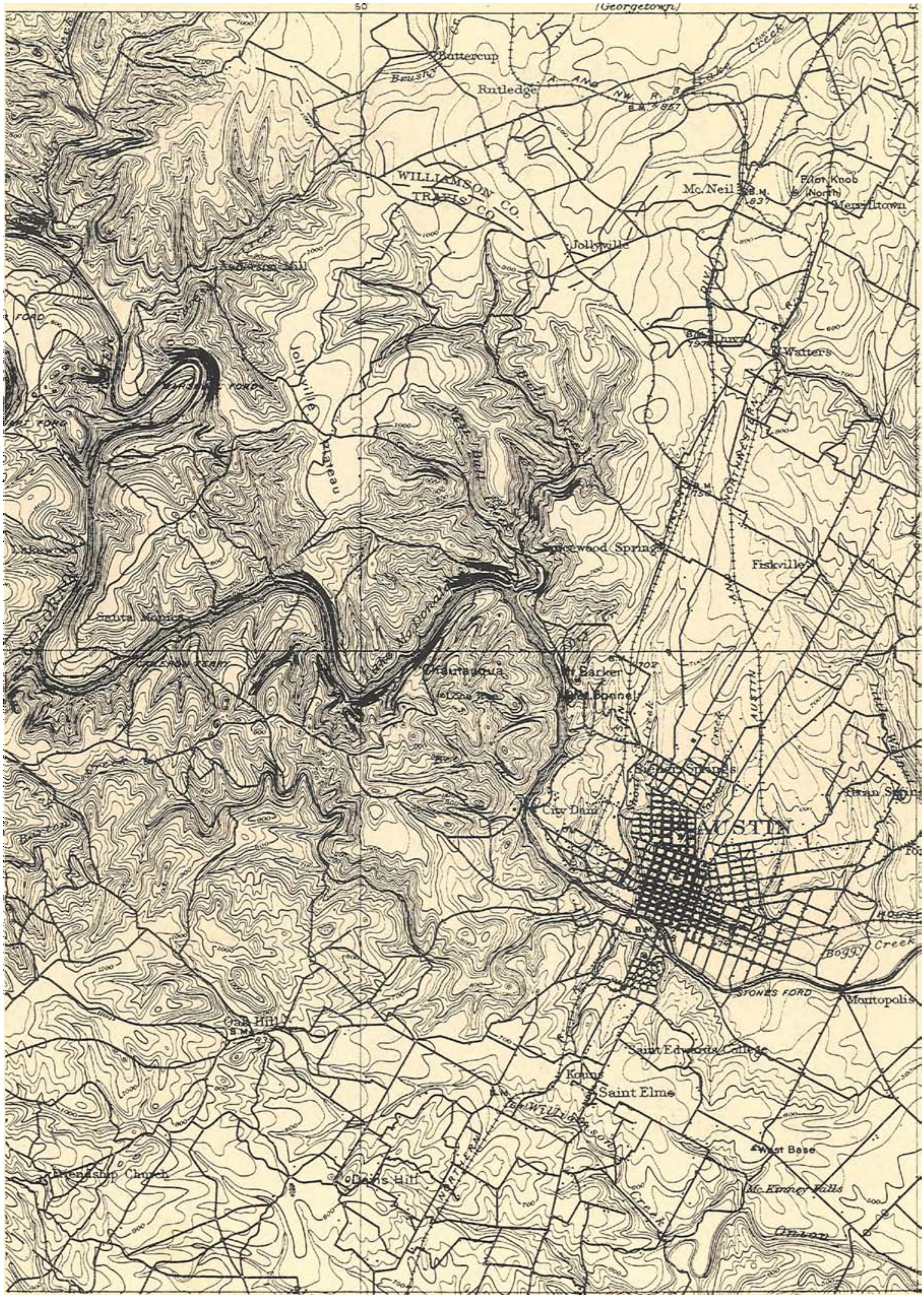
Cover Illustrations

Front Cover: Measured section of basal Edwards Limestone along edge of Jollyville Plateau on Ranch-to-Market Road 2222 (section measured by C. M. Woodruff, Jr. and Laura De La Garza, 1985).

Back Cover: Detail of Austin Folio, circa 1910; topographic contour intervals = 25 ft.



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